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FLOODS, PRECIPITATION, AND DROUGHT

IN THE YELLOW RIVER BASIN

- COMMUNIST CHINA -

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FLOODS, PRECIPITATION, AND DROUGHT
IN THE YELLOW RIVER BASIN

[The following are full translations of two selections from Ti- li Hsueh-pao (Acta Geographica Sinica), Peiping, Volume 22, No 4, November 1956.]

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FLOODS OF THE YELLOW RIVER*

[This is a full translation of an article written by Yeh Yung-i (Hydraulic Research Institute, Peiping) in Ti-li Hsueh-pao (Acta Geographica Sinica), Volume 22, No 4, November 1956, pages 325-337.]

Floods of the Yellow River have always been very serious. In order to eliminate flood disasters, it is necessary to make a thorough study of floods. The aim of this paper is to give a brief account of the flood situation in various sections of the Yellow River.

The hydrological character of a river is the combined product of the natural conditions of the drainage basin. In order to study a river's hydrological character, it is necessary to investigate the natural conditions of the basin, especially the weather and the topography, in addition to making an analysis of the river itself.

A. A Brief Account of the Hydrological Factors of the Yellow River Valley

1. Topography and Vegetation:

The total length of the Yellow River is 4,845 kilometers, and the area of the basin which the river drains is 738,000 square kilometers. The average width of the valley is 152 kilometers. The total descent of the river is 4,368 meters.

*This paper was read before the Geographic Report Meeting.

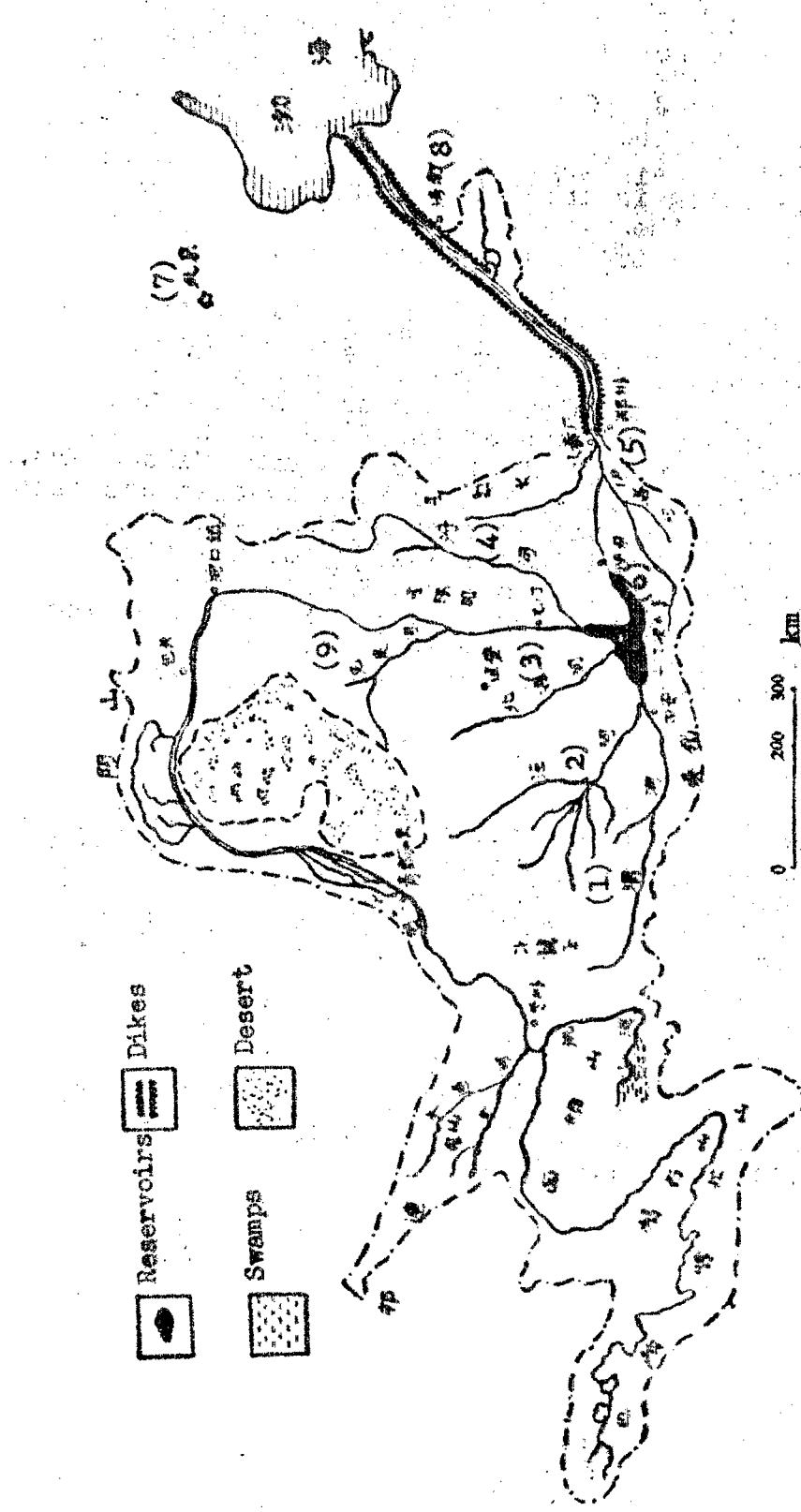


Figure 1. Map of the Yellow River Basin

(1) Wei-ho	(4) Fen-ho	(7) Peiping
(2) Ching-ho	(5) I-lo-ho	(8) Tsinan
(3) Pei-lo-ho	(6) San-men Reservoir	(9) Wu-ting-ho

Above Lung-yang-hsia, the Yellow River flows across the Tsinghai-Tibetan Plateau where the average elevation is about 4,000 meters. From Lung-yan-hsia to Tao-hua-yu in Honan Province, the river flows through a loess plateau which has an average elevation of around 1,000 meters. In the section where the river cuts into the plateau, there are many tributaries. Below Tao-hua-yu, it flows into the North China Plain where the average elevation is about 50 meters. There are dikes on both banks, and the river-bed is higher than the banks. There are very few tributaries in this section.

Above Lung-yang-hsia, the valley of the Yellow River consists mostly of grass-land. There are a number of swamps in this region. Between Lung-yang-hsia and Ch'ing-t'ung-hsia, one half of the land consists of grass-land and the other of farmland. In the valleys of the T'ao Ho and Huang Shui, there is a forest area of about 2,000 square kilometers. The region between Ch'ing-t'ung-hsia and Ho-k'ou-chen consists principally of farmland. In the area below Huang-ho-chen between Shansi and Shensi, and in the valleys of the Ching, Lo, Wei, Fen and the I Ho and Lo Ho the land consists of cultivated loess with the exception of a few rocky mountains and ravines. Of the valleys of the Pei-lo Ho, Wei Ho and I-lo Ho, 7 to 13 percent is forest land. (Fig 1).

2. Rain and Storms:

The Yellow River Valley has seasonal winds and a semi-arid climate. The rainfall in the southeastern part of the valley averages 700 millimeters. It decreases gradually to 100-200 millimeters towards the northwest. From 70 to 80 percent of the rain falls in the two seasons of summer and autumn. This is when floods occur.

Below Ho-k'ou-chen, the highest rainfall per day, according to measurements made over a number of years, is between 100 and 200 millimeters. In the Lanchow area, the rainfall per day is only 50 millimeters. The following table shows the highest rainfall over several years:

Table 1

<u>Location</u>	<u>Rainfall (mm)</u>	<u>Duration(Days)</u>	<u>Month and Year</u>
Pao-chi	237	9	1943.9
Sian	226	12	1950.10
Yu-lin	144	4	1945.7
T'ung-kuan	134	5	1938.10
Shan-hsien	189	9	1949.9
T'ai-yuan	115	3	1933.8
K'ai-feng	397	6	1937.8

Storms of the Yellow River are of two types:

(1) The characteristics of the first type are as follows: heavy rainfall over a small area but of short duration. This type of storm occurs often in July and August. It usually lasts for only a day or two, and the longest duration is not over 5 days. However, it may take place several times a month thus producing successive periods of flood. Storms of this type usually center around the area east of the Ordos in a line from Hu-ho-hao-t'e to T'ien-shui via Yu-lin. In the north Shensi area, a rainfall covers only a small area (a depth of 25 millimeters covers in general only 10 to 20 thousand square kilometers). However, the storms are heavy (two days of rainfall may reach 100-150 millimeters). Storms that occur in the valleys of the Ching, Lo and Wei rivers may cover an area of 100,000 to 200,000 square kilometers.

(2) The second type of storm covers a larger area (in the area above Shan-hsien, a depth of 25 millimeters generally covers an area of 150,000 square kilometers). Also, it is of longer duration (generally lasting 4-5 days). This type of storm usually occurs in September and October. The center of the storm is often in the lower reaches of the Ching, Lo and Wei rivers.

B. Comparison of Floods in Various Sections of the Yellow River

1. Floods at Lanchow:

The drainage basin of the Yellow River above Lanchow has an area of 216,000 square kilometers. The marshes, grass-lands, forests and lakes in the region regulate the flow of the river to some extent. Thus the rise and fall of floods at Lanchow is comparatively mild. A flood usually lasts from one to two months (Fig 2). The rise and fall of the flow as indicated by the curves is due to the rainfall in the neighboring areas above Lanchow.

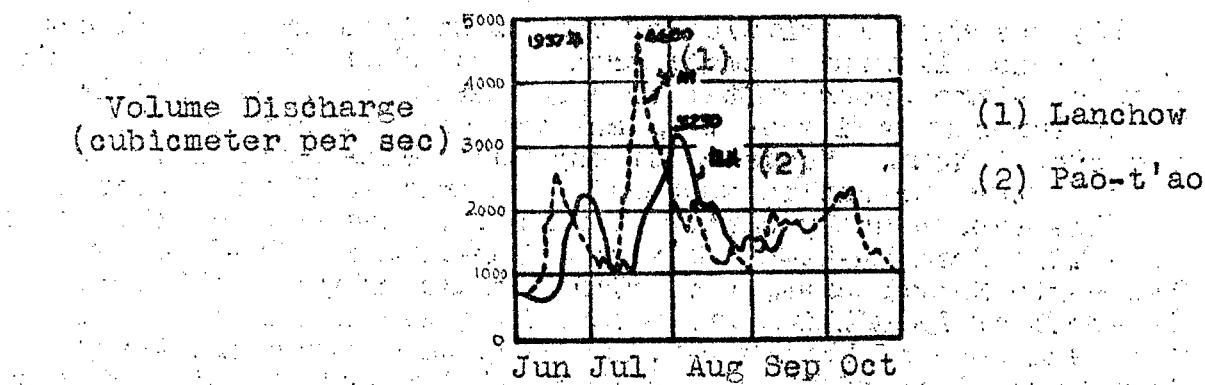


Figure 2

Curves Showing the Flood Discharge in a Typical Year at the Lanchow Station and the Pao-t'ou Station of the Yellow River

Considering the size of the drainage basin above Lanchow, the maximum discharge at Lanchow is not very large. In normal years, it does not exceed 5,000 cubic meters per second. Since 1934 when records were kept, the biggest flood recorded occurred on 13 September 1946. The highest water mark noted at the Hydrological Station at Lanchow (100-200 meters below the Yellow River Bridge) was 1,516.22 meters (above Ta-ku base), and the maximum discharge was 5,900 cubic meters per second. The average maximum discharge over the years was 3,900 cubic meters per second. The variation coefficient C_v is 0.25. If the skew of coefficient C_s is equal to $4C_v$, the peak discharge that occurs once in a century would be 6,800 cubic meters per second, and the peak discharge that would occur once in a thousand years would be 8,200 cubic meters per second. The greatest flood in history is known to have occurred between 13-18 July 1904 (30th year of Kuang Hsu). Then, the highest water mark at Lanchow was 1,517.0 meters and the maximum discharge was 7,500 cubic meters per second. In 1946 and 1904 a part of the city of Lanchow was covered by water.

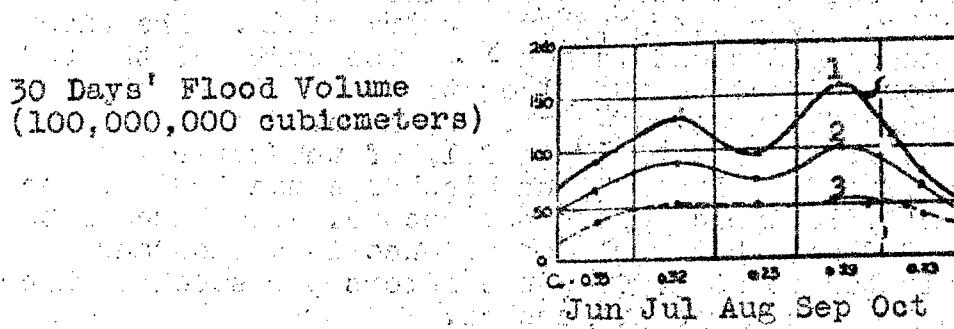


Figure 3

Distribution of Flood Volume over 30 Day Periods at the Lanchow Station of the Yellow River

- (1) Once in a thousand years.
- (2) Maximum measured.
- (3) Average of measurements.

The total for 45 days of maximum flood discharge of the Yellow River at the Lanchow Station reached 14 billion cubic meters. The average over the years is 9,660,000,000 cubic meters. The C_v value is 0.24. If C_s is equal to $2C_v$, the volume of a flood occurring once in a thousand years is estimated to be 18.4 billion cubic meters.

The biggest floods of the Yellow River at the Lanchow Station usually occur in July and September. This is due to the distribution of rainfall in this area (Fig 3).

2. Between Lanchow and Pao-t'ou:

Between Lanchow and Ch'ing-t'ung-hsia, the Yellow River flows through mountainous areas and the area of the drainage basin is increased by 61,000 square kilometers. The rainfall is light in this region (the annual rainfall is less than 300 millimeters, and the flood discharge is not increased very much by it. From Ch'ing-t'ung-hsia to Ho-k'ou-chen, the river runs a distance of 869 kilometers and the drainage basin is increased by 105,000 square kilometers. In this region, the Yellow River flows through a dry plain. The river bed is wide and the descent is gentle. The width of the bed has a regulatory effect on the flood that comes down the river from above Ch'ing-t'ung-hsia, which somewhat reduces the flood discharge. The rise and fall of the water mark is also less (Fig 2). The maximum discharge measured at Pao-t'ou has been 4,310 cubic meters per second. The discharge of the kind of flood that would occur once in a thousand years is estimated to be 5,900 cubic meters per second, which is less than the discharge at Lanchow.

3. From Ho-k'ou-chen to Shan-hsien:

Below Ho-k'ou-chen, the Yellow River has cut a ravine between Shansi and Shensi. Many small tributaries enter the river in this section. The slope of the terrain is quite steep. Violent storms are frequent in the summer and autumn. Thus the discharge at the Lung-men hydrological station often exceeds 10,000 cubic meters per second and the flood level rises and falls very rapidly (Fig 6). However, the floods last for only a few days, and they are quite different from those which occur on the Yellow River in the vicinity of Lanchow and Pao-t'ou.

Such tributaries as the Fen Ho, Pai-lo Ho and Wei Ho (including the Ching Ho) enter the Yellow River between Lung-men and T'ung-kuan. Rain storms are heavy in this area, and they produce heavy flooding.

The shape of the drainage basin of the Fen Ho is narrow and long. Storms are not heavy in this area and the middle and lower reaches of the river flow through a basin where the channel is wide. The flood water is used to irrigate farmland along the banks of the river. According to the measurements recorded at the Ho-chin Hydrological Station at the mouth of the Fen Ho, the flood discharge is no more than 3,320 cubic meters per second and the annual average is only 880 cubic meters per second. Considering that there is a basin area of 38,700 square kilometer above the station, the discharge is small.

The drainage basin of the Ching Ho is like a fan. It is situated on the southeastern slope of the Liu-p'an Shan. Since storms are heavy and there are many tributaries the floods measured at the Chang-chia-shan Hydrological Station at the mouth of the Ching Ho are often very big. The largest discharge measured reached 9,400 cubic meters per second. The biggest floods occur in August.

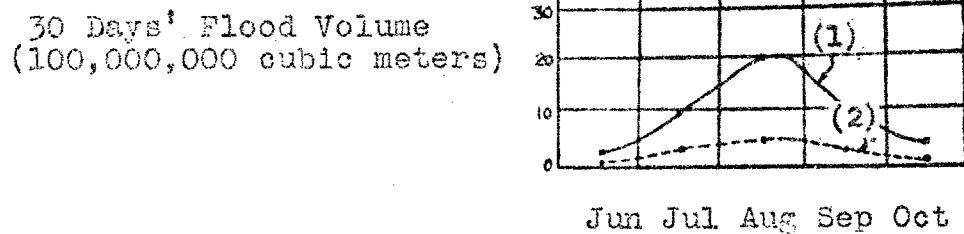


Figure 4

Distribution of Flood Volume over 30 Day Periods at the Chang-chia-shan Station on the Ching Ho.

(1) Maximum measured.

(2) Average.

The storms in the drainage basin of the Pei-lo Ho are heavy but of short duration. Thus the total flood volume is small even though the flood peaks are high. The floods are similar to those on the rivers in northern Shensi.

The storms along the Wei Ho are of longer duration. Thus although the flood peaks are smaller [than on the Ching Ho], the total volume is greater. This phenomenon is partially caused by the long and narrow shape of the drainage basin of the Wei Ho. Measurements recorded at the Hsien-yang station show that the September volume is the largest (Fig 5). The Wei Ho valley is an area of autumn rain; a record of such rains frequently appear in historical documents. The local histories of Li-ch'üan, Ching-yang-hsien and Ta-li-hsien all record rains lasting from 40 to 50 days in the autumn of 1898 (24th year of Kuang-hsu), 1906 (32nd year of Kuang-hsu) and 1910 (2nd year of Hsuan-t'ung).

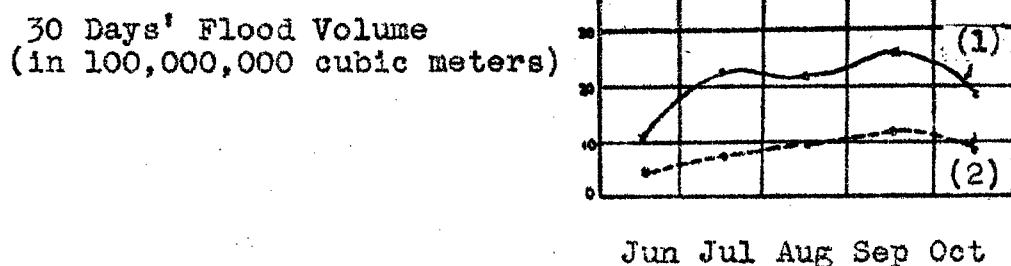


Figure 5
Distribution of Flood Volume over
30 Day Periods Recorded at the Hsien-
yang Station on the Wei Ho.

(1) Maximum measured.

(2) Average.

Table 2
Statistical Data on Flood Characteristics of
the Yellow River and Its Tributaries

Rivers	Stations	Peak Discharge (m^3/second)						Total Flood Volume (100 million m^3)					
		Basin Area sq km	Data Yr	Max	Yr	Avg	C_s	C_g/C_p	1000 Yrs	C_s/C_p	1000 Yrs	C_s/C_p	1000 Yrs
Yellow	Lanchow	216,000	21	4,400	1916	3,850	0.25	4	3,200	17.6	45	140	1946
Yellow	Pao-t'ou	356,000	16	4,310	1943	2,710	0.26	4	5,900	9.9	45	117	1943
Yellow	Lung-men	494,900	9	17,000	1954	10,330	0.40	4	33,000	47.0	45	134	1937
Yellow	Shan-hsien	684,000	32	18,600	1933	8,740	0.43	4	30,000	36.2	45	205	1949
Fen Ho	Ho-shin	38,700	9	3,320	1954	882	1.06	4	8,800	44.7	7	9,20	1954
Pei-lo Ho	Chuang-t'ou	26,700	21	5,030	1943	1,250	1.09	4	12,000	73.4	7	4.24	1940
Wei Ho	Hua-hsien	105,000	15	12,900	1933	4,760	0.56	4	22,000	67.8	7	26.6	1933
Wei Ho	Hsien-yang	49,800	21	7,220	1954	3,150	0.38	4	9,200	41.2	7	12.6	1937
Wei Ho	Chang-shia-shan	41,800	23	9,410	1933	2,740	0.89	4	22,000	108	7	14.7	1933
I-lo Ho	Hei-shih-kuan	17,700	19	8,630	1935	3,600	0.78	2	18,500	139	7	18.1	1937
Ch'ien Ho	Hsiao-tung	12,100	10	3,050	1954	1,150	0.72	2	5,600	50.5	7	6.2	1954

If floods should occur at the same time in the Shansi-Shensi drainage basin and in the Ching Ho, Lo Ho and Wei Ho region, the flood at Shan-hsien would be very great (Fig 6).

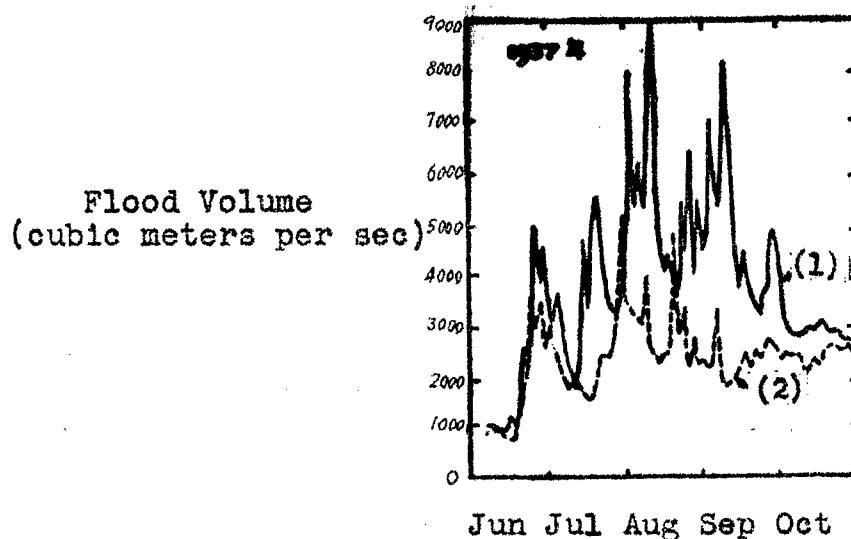


Figure 6

Flood Volume at the Lung-men and Shan-hsien Stations of the Yellow River in 1937.

(1) Shan-hsien (2) Lung-men

4. Below Shan-hsien:

The I-ko, Ho and Ch'in Ho enter the Yellow River between Shan-hsien and the Peiping--Hankow Railway. Storms are very heavy in this area, and floods sometimes threaten the dikes along the lower reaches of the river.

Below the Peiping--Hankow Railway the Ta-wen Ho enters the Yellow River through Tung-p'ing-hu. The channel of the river serves to regulate and reduce the flow (Fig 7).

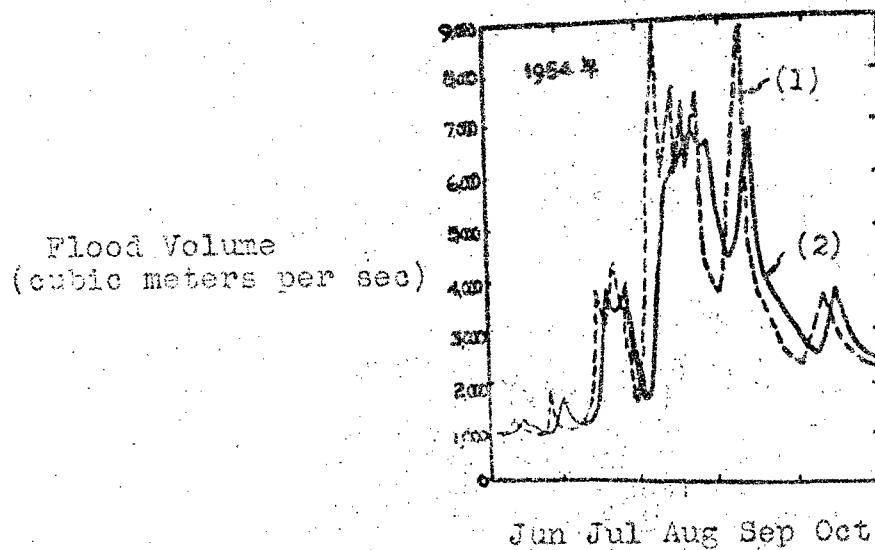


Figure 7

Flood Volume at the Ch'in-ch'ang Station and the Lo-k'ou Station of the Yellow River in 1954.

(1) Ch'in-ch'ang (2) Lo-k'ou

C. Floods at Shan-hsien

Shan-hsien is 22 kilometers above the site of the San-men-hsia Dam. A hydrological station was established there in 1919, and it has now collected data for 32 years. There were several years when no observations were made. Since there is no large tributary [entering the Yellow River] between Shan-hsien and San-men-hsia the hydrological data of Shan-hsien may be used directly for designing the reservoir at San-men-hsia.

1. The Biggest Flood:

A compilation of the records in 1955 showed that the biggest flood on record occurred on 10 August 1935. The water mark then reached 299.14 meters (above Ta-ku base) and the

discharge was 18,500 cubic meters per second. The previous estimate made was 22,000 cubic meters per second. The second largest flood occurred on 4 August 1942. The water mark then reached 298.66 meters and the discharge 16,400 cubic meters per second. The smallest occurred on 4 August 1924, when the discharge was 3,250 cubic meters per second. The average volume over the years of greatest discharge is 8,740 cubic meters per second. The C_v value is 0.43. The estimated discharge for a flood that would occur once in a thousand years is 30,000 cubic meters per second ($C_s=4C_v$).

According to investigation, the biggest flood in history occurred on 10 August 1943 (23rd year of Tao Kuang). The people in the Shan-hsien area have the saying that "in the 23rd year of Tao Kuang, the Yellow River rose up to heaven and wiped out T'ai-yang-tu and Wan-ching-t'an (T'ai-yang-tu and Wan-ching-t'an are places in Shan Hsien). From traces of the flood, the maximum discharge in that year is estimated at 30,000 cubic meters per second.

The average volume of the biggest thirty day and forty-five day floods over the years were 8,750,000,000 cubic meters and 12.1 billion cubic meters respectively. The C_v values are both 0.34. The volume of such floods which might occur once in a thousand years are estimated to be 18 billion cubic meters and 29 billion cubic meters respectively.

2. Floods in Various Months:

The volume of the Yellow River floods vary from month to month. After the first 10 days of June, the maximum flood discharge increases rapidly. It reaches its peak in the first 10 days of August and then decreases gradually (Fig 8). If the same figures are assumed to exist for the whole period when reservoirs are designed, their capacity will not be fully utilized, thus incurring waste. We must therefore ascertain the flood discharge of each month and design our conservation projects accordingly.

There are two flood peaks at Shan-hsien each year. The first occurs in the period between the middle of July and the middle of August, and the second occurs in September. According to measurements, the maximum discharge of the latter exceeds the former (Fig 9 and 10). The peak flow of the former is due to the frequent storms in the Shansi-Shensi

region which are short in duration and cover a small area. The peak flow of the latter is due to the heavy rain that occurs frequently in the region above Lanchow and in the Wei Ho area in September. The run-off coefficient of the latter region is greater than that of the loess plateau of northern Shensi. Thus bigger floods occur in September.

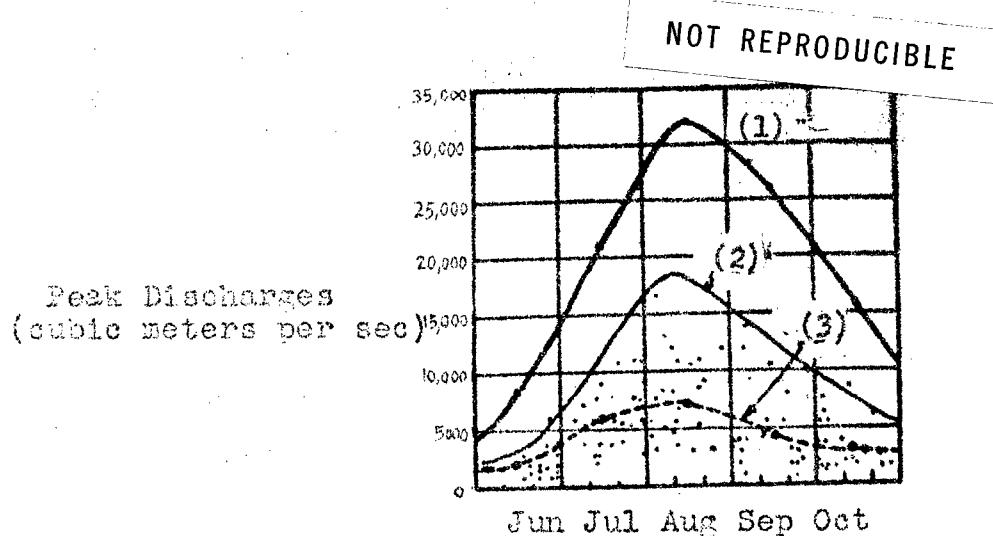


Figure 8

The Distribution of the Maximum Discharges in Various Months during the Flood Season at the Shan-hsien Station of the Yellow River.

- (1) Once in a thousand years for various months.
- (2) Actual measurements for various months
- (3) Average of measurements for various months.

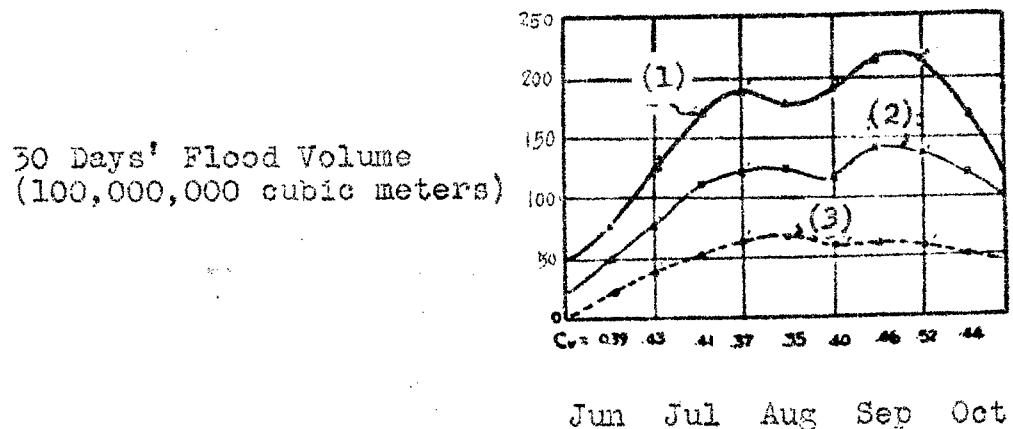


Figure 9

Distribution of Flood Volume over
30 Day Periods in Various Months
During the Flood Period at the Shan-
hsien Station of the Yellow River.

- (1) Once in a thousand years.
- (2) Maximum measured.
- (3) Average of measurements.

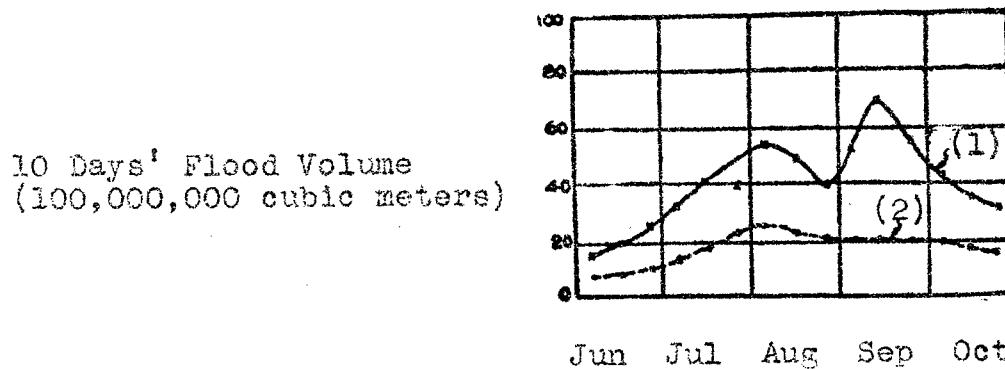


Figure 10

Distribution of Flood Volume over Ten
Day Periods During the Flood Period
at the Shan-hsien Station of the
Yellow River.

- (1) Maximum measured.
- (2) Average of measurements.

D. Sources of the Shan-hsien Flood

1. Sources of the flood:

From analysis of the records of many years, we can see that in years when the total flood volume is small at Shan-hsien, the water that comes from the main stream constitutes over 80 percent of that volume, while that which comes from the Wei Ho (including the Ching Ho and Pei-lo Ho) is less than 20 percent (Fig 11). As the flood volume at Shan-hsien increases, the percentage of the water that comes from the main stream diminishes until it is less than 60 percent and the percentage of the water that comes from the Wei Ho (including the Ching Ho and Pei-lo Ho) increases until it is more than 40 percent. It is estimated that during a flood which occurs once in 100 years or once in 1,000 years, the amounts of water from the two sources is almost equal. It is even possible that the flow from the Wei Ho may constitute a larger percentage.

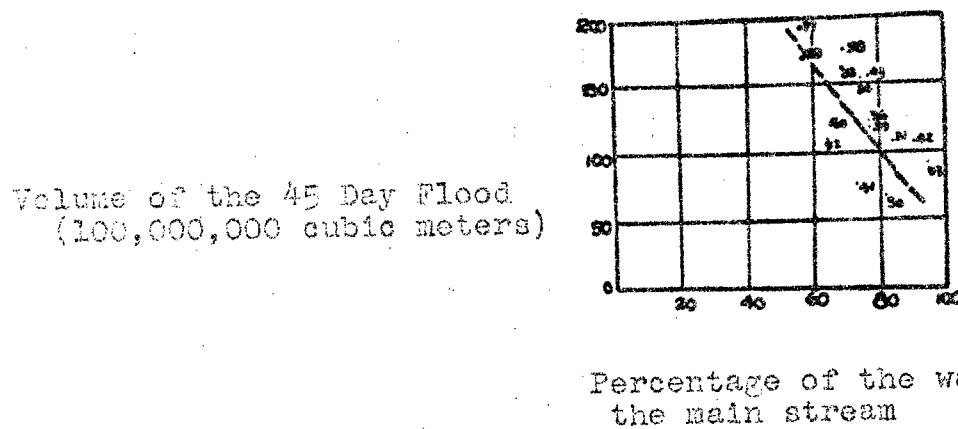


Figure 11

Analysis of the Sources of the Flood
Volume of the Yellow River at Shan-hsien

The percentage from the area above Hsien-yang in the total flood flow of the Wei Ho at Shan-hsien:

In the years when the flood at Shan-hsien is small, the variation is greater (two percent to 19 percent); in the years when the flood is big, the variation is smaller (15 percent to 20 percent). The percentage of the water from the Ching Ho is one percent to 10 percent. The average is five percent. The percentage of water from the Pei-lo Ho is 0.1 percent to 6.1 percent. The average is 2 percent.

On the main stream itself, the water that comes from the river above Pao-t'ou constitutes a large percentage--40 percent to 90 percent. As the flood volume at Shan-hsien increases, the percentage decreases. That is to say, the greater the flood volume at Shan-hsien, the higher will be the percentage of the water from the Ching Ho, Lo Ho and Wei Ho (Fig 12).

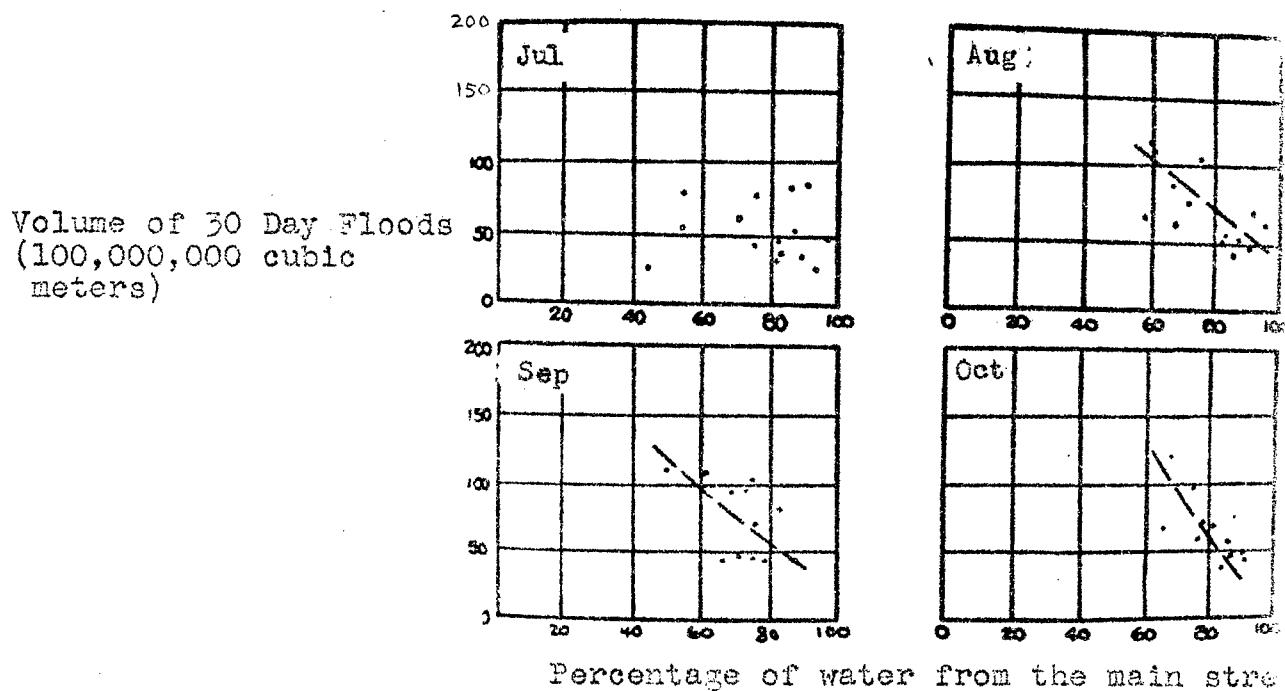


Figure 12

Analysis of the Sources of Flood Discharge in Various Months at Shan-hsien

2. Composition of the Discharges at Flood Peaks:

Of the discharge at Shan-hsien, the variability of the flow from Pao-t'ou is not great--being 700 to 3,000 cubic meters per second, with an average of 1,600 cubic meters per second. When the discharge during the flood peak at Shan-hsien is small, the flow from Pao-t'ou is also small. Similarly, the corresponding flow from the Fen Ho in past years has not been more than several ten to several hundred cubic meters per second.

The discharge at Shan-hsien comes principally from the area between Pao-t'ou and Lung-men and the area of the Ching, Lo and Wei rivers. At times, the flood of a single river may cause a principal flood peak at Shan-hsien--as in 1936, 1942, 1950 and 1952 for example. The big floods at Shan-hsien, such as those which occurred in 1933 and 1954, are caused by the flooding of rivers of two different areas at the same time. The flood waters from the area between Pao-t'ou and Lung-men have a greater effect on the larger peak discharges at Shan-hsien. During floods on those rivers, the peak discharges at Lung-men are 50 percent greater than at Shan-hsien.

3. Understanding the Sources of Floods at Shan-hsien from a Study of Flood History:

In 1955, the Yellow River Conservation Commission and the Shensi Water Conservancy Bureau made a field investigation of the historical floods of the main stream of the Yellow River between Ho-k'ou-chen and Hsiao-lang-ti and of the following tributaries: the K'u-yeh Ho, Wu-ting Ho, Ching Ho, Pei-lo Ho, Wei Ho, I-lo Ho and Ch'in Ho. After making a detailed study of the years in which the floods occurred, their size, their traces and other factors, the following conclusions were reached:

(1) When exceptionally big floods occurred at Shan-hsien, big floods also took place between Pao-t'ou and Lung-men and in the Ching and Wei rivers. However, the floods were not exceptionally big for the rivers. For instance, during the flood at Shan-hsien in 1843, there was no flooding in the main river or in the tributaries above T'ung-kuan. However, heavy flooding occurred between Shansi and Shensi and in the Wei Ho. From the memorial on rainfall submitted by the Governor of Shansi, we know that in 1843 three, four and five

inches of rain fell on the 7, 8 and 9 of August respectively in the area of Hsing-hsien, Ho-ch'u, Lin-hsien and Pao-te in northern Shensi. Heavy rain also fell in the area of Hsu-kou, T'ai-yuan, Wen-shui and Chiao-ch'eng in central Shansi. In his memorial on 21 August, Governor Li Hsin-yuan of Shensi also mentioned the flooding of several chou and hsien along the Wei Ho caused by a rush of water from the mountains. He also noted that from one to three inches of rain fell during August 6-9 in the area of Sian, Feng-hsuan, Han-chung and Yu-lin.

(2) Exceptionally large floods occurred on different rivers in different years...the Ching Ho in 1847 and 1911, the Pei-lo Ho in 1839 and 1855, the Wei Ho in 1849 and 1898, and at Lung-men in 1942 and 1896. In all these years, no exceptionally large flood occurred at Shan-hsien. It is thus clear that even an exceptionally large flood on any single river cannot bring about an exceptionally large flood at Shan-hsien. However, exceptionally heavy floods above Lung-men do have an important effect on the flood at Shan-hsien; for instance, the floods of 1896 and 1942.

(3) The discharge of the Ching Ho at flood peak is quite great. In 1847, it reached 18,000 cubic meters per second. This situation is worth our attention. A local proverb says: "We are not afraid of the 18 branches of the nine streams; we are afraid only of the torrential rain over P'ing-liang and Yang-ch'ing." This indicates that flooding on the Ching Ho is chiefly caused by rain over the P'ing-liang and Yang-ch'ing area.

(4) Big floods at Lung-men are mostly originated in such tributaries as the Wu-ting Ho, K'u-yeh Ho and Huang-fu-ch'uan, and very possibly from the upper reaches of these tributaries.

E. Relation Between Floods Occurring Above and Below San-men-hsia

Between San-men-hsia and Ch'in-ch'ang, the I-lo Ho and Ch'in Ho join the Yellow River, which increases the area of the drainage basin by 40,000 square kilometers. Also, the discharge from the reservoir at San-men-hsia during the flood periods is augmented by the floods of this area. It is thus necessary to know the volume of discharge of these

rivers between San-men-hsia and Ch'in-ch'ang and how it joins the discharge from the area above San-men-hsia. On the basis of past records, we have the following situations:

(1) When there are big floods above Shan-hsien, there may not be any great flooding in the valleys of the I-lo Ho and Ch'in Ho. For instance, the flood volume at Shan-hsien in 1933 was the greatest ever measured and that of 1942 was the second greatest. According to investigation, the I-lo Ho and Ch'in Ho did not have big floods in either year.

(2) When a flood above Shan-hsien is not heavy, floods on the I-lo Ho and Ch'in Ho might be big. For instance, according to investigation, the I-lo Ho flood of 1931 was the largest over the years. And, the I-lo Ho peak discharges in 1935, 1937 and 1954 were all around 8,000 cubic meters per second, while the peak discharges at Shan-hsien were from 5,000 to 6,000 cubic meters per second.

The Wei Ho and I-lo Ho are on the same latitude. Moreover, both are sheltered by the Ch'in-ling Shan and the Funiu Shan in the south. Thus the two rivers often flood at the same time. According to data covering the eight years from 1934 to 1937 and from 1950 to 1954, flooding occurred on the Wei Ho 58 times and on the I-lo Ho 46 times. That is to say, there is an 80 percent chance of the latter flooding when the former does. On the other hand, floods that occur above Lung-men have little effect on the I-lo Ho. That is because the storms that occur above Lung-men seldom reach that river. This is the reason why flooding was minor on the I-lo Ho in 1933 and 1942 when the floods above Shan-hsien were heavy.

The Ch'in Ho is in the north while the I-lo Ho is in the south. Exceptionally serious floods on these rivers do not take place at the same time. According to investigation, exceptional flooding of the I-lo Ho took place in 1935 and 1931, while on the Ch'in Ho they took place in 1895 and 1943. However, as the lower reaches of these two rivers are close to each other, it is possible for the floods in these parts to come together at the same time. Floods in this area are, however, not very big since this is an area of plains and hills.

Floods on the I-lo Ho system almost always occur at the same time, while on the Ch'in Ho and its tributary, the Tan Ho, they seldom occur at the same time. According to investigation, the Tan Ho had its biggest floods in 1900 and 1932.

These were not the years when floods on the Ch'in Ho were the heaviest.

The channel of the lower reaches of the Yellow River above Ai-shan in Shantung Province has a width of 5-10 kilometers. Thus the flood peaks diminish as they pass through this stretch of the river. However, the channel below Ai-shan is narrower with a width of generally around one kilometer. Thus the capacity of the channel is limited.

The decrease in the flood peak in the lower reaches of the river varies according to the following circumstances:

(1) The decrease is greater when the flood peak, even though high, is of short duration.

(2) The capacity of the channel is less when the volume of the original flow of the channel is large and when the water level is high.

(3) When flooding from the Ta-wen Ho fills up Tung-p'ing Lake first, the capacity of the latter to retain flood waters of the Yellow River is reduced.

During the flood which occurred in the last 10 days of August 1953, the channel between the Ch'in-ch'ang and Sun-k'ou held 880 million cubic meters of water (Fig 13). By making an estimate based on a cross section of the channel the retention capacity from Ch'in-ch'ang to Lo-k'ou, measured from the mark which indicates the level of safe discharge in the lower reaches of the river to be 8,000 cubic meters per second to the water mark of the allowable flood discharge at a moment, is 3.2 billion cubic meters. However, since the flood peak moves down the river constantly the water in each cross section cannot reach the highest mark at the same time. Therefore, the retention capacities of 880 million cubic meters and 3.2 billion estimated above cannot be treated in the same way as the capacity of a reservoir.

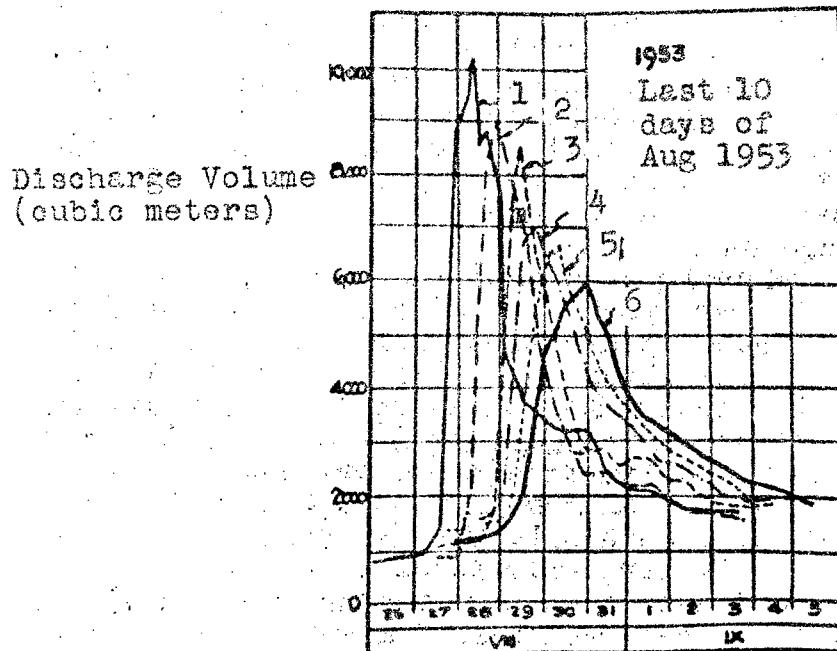


Figure 13

Progress of the Flood in the Lower Reaches of the Yellow River 1953

- (1) Ch'in-ch'ang (4) Sun-k'ou
- (2) Yang-lo-t'an (5) Ai-shan
- (3) Su-ssu-chuang (6) Lo-k'cu

F. Plans for the Control of Yellow River Floods

Having come to understand the flood character of the Yellow River, we now make the following suggestions on flood control:

- (1) Should reservoirs be built or should the height of the dikes be increased?

The floods that come from the area above Ch'in-ch'an have very high peak discharges while the safe discharge capacity

of the lower reaches of the river is small. If dikes are used to control the floods, their height must be greatly increased. The dikes on the banks of the lower reaches of the Yellow River are very long. To increase the height along the full length of these dikes would entail very high expenditures. Moreover, since the water contains a large amount of silt which constantly fills up the river bed the height of the dikes would have to be constantly increased. And, the dikes themselves constitute a danger for they are constantly exposed to the pressure of the current.

If reservoirs are used to control the floods, they will not only reduce the flood peaks but also regulate the flow for the purposes of power generation, irrigation and navigation. Thus flood control of the Yellow River should be achieved principally through the building of reservoirs and secondly through improvement of the channel in the lower reaches so as to increase its discharge capacity. As to the Yangtze River and the Han-shui it is not possible to create a reservoir large enough to retain flood waters because of the excessively large discharge. (And even if it were possible it would not be economical to build one.) Thus in addition to building reservoirs on the upper and middle reaches to reduce a part of the flood, special attention must be paid to the improvement of the channel of the lower reaches, and to measures for breaking up the flood and eliminating it.

(2) Where should reservoirs be built? From the above sections, we have learned that the floods that menace the lower reaches of the Yellow River are from three sources: First are the many tributaries in the section between Ho-k'ou-chen and Lung-men in the Shansi-Shensi area. Secondly, there are flood waters from the Ching Ho, Lo Ho and Wei Ho systems. And thirdly, there are the floods from the I-lo Ho and Ch'in Ho system.

We must note that in 1933 when the flood discharge at Shan-hsien reached 18,500 cubic meters per second, the flood that came from Pao-t'ou amounted to only 2,000-3,000 cubic meters per second. Thus even if all the water from the area above Pao-t'ou were under control, it would not help very much. We must also note that the exceptionally big floods at Shan-hsien are caused by flooding on all the tributaries. Therefore, to control these floods it is necessary to build reservoirs on all the larger tributaries. This will be very expensive and will take a lot of time. Hence, reservoirs should not be built above T'ung-kuan but below that point.

The reservoir on the main stream of the Yellow River below T'ung-kuan should be built below the point where the I-lo Ho joins the river and above the point where the dike begins. In this way, all phases of a whole flood can be put under control. However, this section of the river does not have the topographical and geological conditions favorable to construction of a dam. Thus San-men-hsia which possesses such conditions has to be chosen as the site. The reservoir here has a large capacity and it can completely control any "thousand-year flood" (floods that [figuratively] occur once in a thousand years) above the dam. However, the I-lo Ho and Ch'in Ho enter the Yellow River below San-men-hsia. Hence, the flood flow from these rivers is still a menace to the channel in the lower reaches. It is, therefore, necessary to take measures to control the flood in this area.

(3) How should the reservoir be used to control floods?

The volume of the Yellow River flood varies from month to month. In order to utilize the reservoir economically and effectively, we should provide the necessary capacity for flood control according to the flood volume of each month. Most of the flood peaks in July and August are high, but the volume is not very large; while in September and October, the flood peaks are low but their volume large. Thus the reservoir should be worked differently in different months. The flood from Lung-men seldom combines with the flood from the I-lo Ho. The water from the reservoir may, therefore, be safely discharged. Flood waters from the Wei Ho may possibly join those from the I-lo Ho. When this happens, attention should be paid to the amount of water discharged from the reservoir.

G. Conclusion

(1) In order to understand the floods of a river, it is necessary to fully understand the natural geographical factors, including the climate, topography, soil, vegetation, etc., of the drainage basin. That is to say, in studying a hydrological phenomenon, it is necessary to analyse the environmental conditions in addition to making a comprehensive study of the phenomenon itself.

(2) Since the floods of the Yellow River are caused by seasonal storms, they have a strong seasonal character. And,

as the rainfall differs each month, the volume and form of the flooding also varies from month to month. In studying floods, we must pay attention to their seasonal character. This principle may be applied to the study of any river in the eastern part of China.

(3) As the Yellow River flows through areas with different climates, the nature of its flood also varies in accordance with the changing conditions. Therefore, in analyzing a flood we must pay attention to the characteristics of the area the river passes through.

(4) The sources of a flood above a dam and the combining of flood waters above and below a dam are new topics in the study of floods. These topics may be solved through the use of statistics and analysis of the geographical characteristics.

(5) The investigation of historical floods has a very important bearing on the study of rivers on which there is a shortage of data or of rivers which have not yet been fully studied. Besides helping to understand possible flood levels and flow volumes, investigation of floods can also help us understand the character of their rise and fall, rainfalls, flood sources and the joining of floods from different areas.

Concerning the nature of the Yellow River floods, we must admit that there are still many problems that we do not understand very fully; especially such problems as the formation of storms, the relation between storms and run-off, the joining of floods, the progress of floods in the river channels and similar problems. We must continue to study all of these.

Reference Materials

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THE PLUVIAL REGIME AND DROUGHTS OF THE YELLOW RIVER BASIN*

[This is a full translation of an article written by Yang Chien-ch'u and Hsu Shu-ying, Institute of Geophysics, Academia Sinica in Ti-li Hsueh-pao (Acta Geographica Sinica), Volume 22, No 4, November 1956, pages 339-351.]

In 1954 the Institute of Geophysics of the Academia Sinica and the Yellow River Planning Commission jointly did some rather comprehensive work on precipitation in the Yellow River Basin. The work included compiling, editing, analyzing, and research on materials concerned with precipitation.

As a result, "A Precipitation Atlas of the Yellow River Basin" and a special issue, entitled "The Precipitation of the Yellow River Basin" were published in 1955. The former includes 143 various diagrams and maps on precipitation and the latter seven articles which discuss the problems of precipitation, storms and flood peaks, droughts and so forth.

This article is based on the above-mentioned works and attempts to give a general account of the pluvial regime and the droughts of the Yellow River Basin.

I. The Characteristics in the Seasonal Variation of Precipitation in the Yellow River Basin

The distribution of the mean annual precipitation in the Yellow River Basin generally decreases from southeast to northwest (Fig 1). It is heaviest in the mountain areas of T'ai Shan and I Shan in Shantung Province, and lightest along the river from Teng-k'ou to Chung-ning above the Ordos. The average annual precipitation in the various regions of the Yellow River Basin generally is 150 to 950 millimeters (Reference 1).

*This article was read before the Meeting for Reporting Academic Learning of the Geographic Society of China.

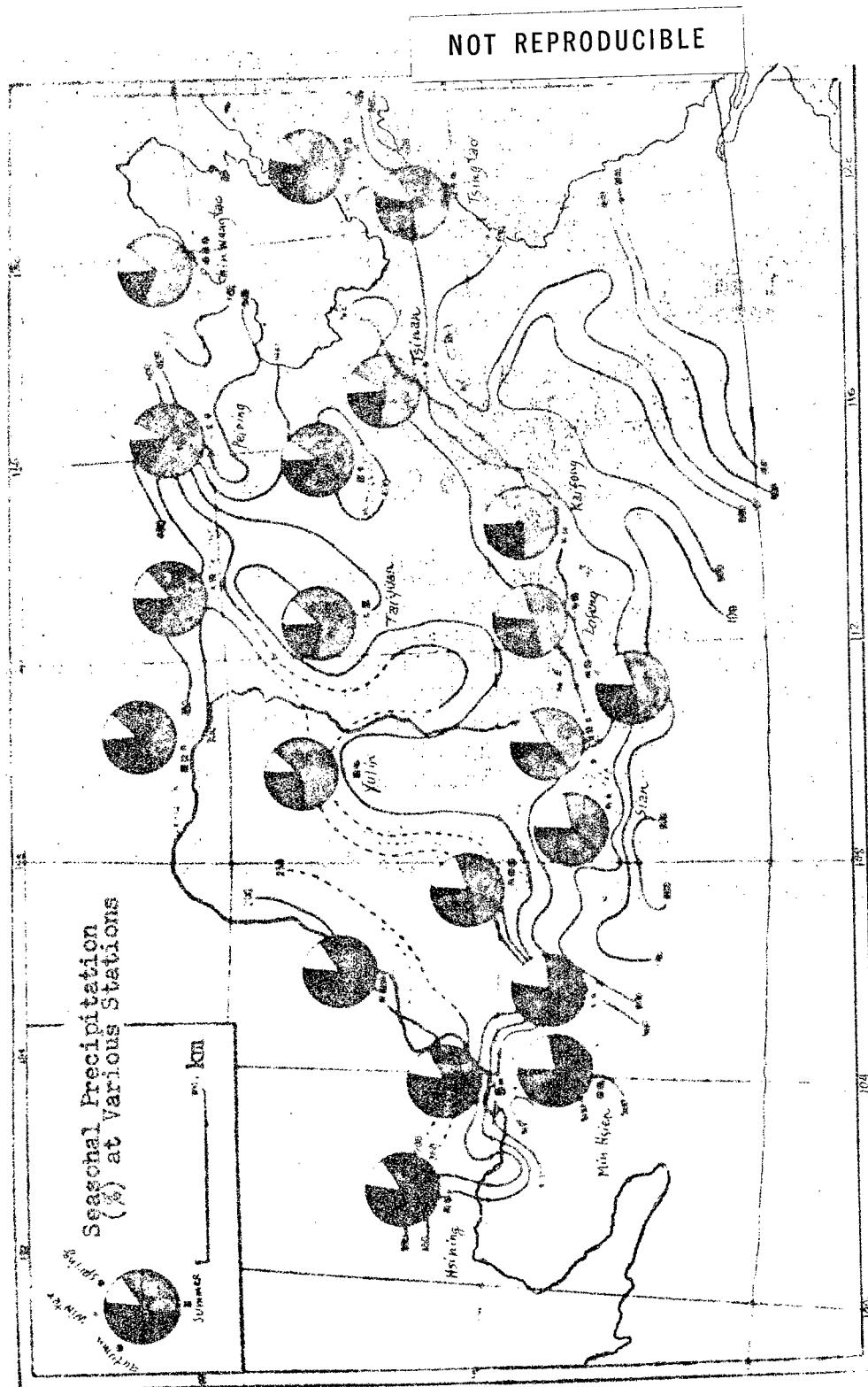


Figure 1 Distribution of Annual and Seasonal Precipitation
in the Yellow River Basin

As shown in Figure 1, the seasonal variation of precipitation in the Yellow River Basin is very pronounced. The precipitation in the various areas is highly concentrated in the summer season (June to August). The summer rainfall in the overwhelming majority of areas throughout the entire basin amounts to more than a half of the annual precipitation. This is particularly true of the Hopei Plain, where summer rainfall occupies about three-quarters of the annual amount, thus making it the region with the most concentrated summer rainfall in China.

Autumn precipitation is slightly more than that of spring in most areas of the Yellow River Basin; this variation is particularly distinct in the Wei Ho Basin and the upper reaches of the Yellow River. Precipitation in winter is usually scarce and amounts to only 1 to 7 percent of the annual figure in most areas.

With the exception of the eastern part of the basin, the distribution of the average annual number of rainy days generally decreases from south to north (Figure 2). The area between Min Hsien and T'ien-shui has the greatest number of rainy days in the entire basin, whereas the southern part of Hopei Province, the eastern and the western slopes of the T'ai-heng Shan, and the Ordos and the area west of it have the least number of days with rain.

The average annual number of rainy days in the various areas throughout the basin is within the scope of 30 to 115 days (Reference 1).

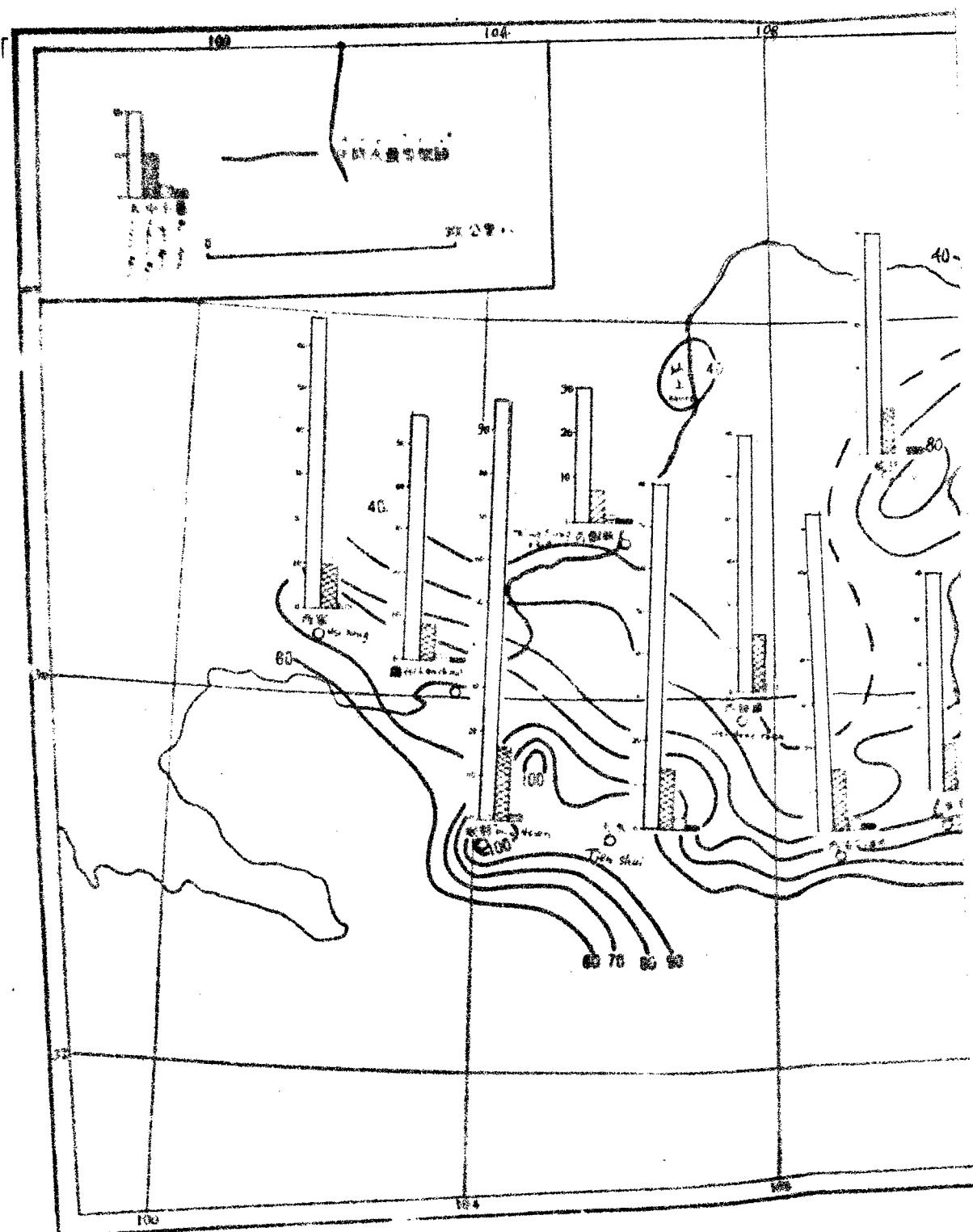
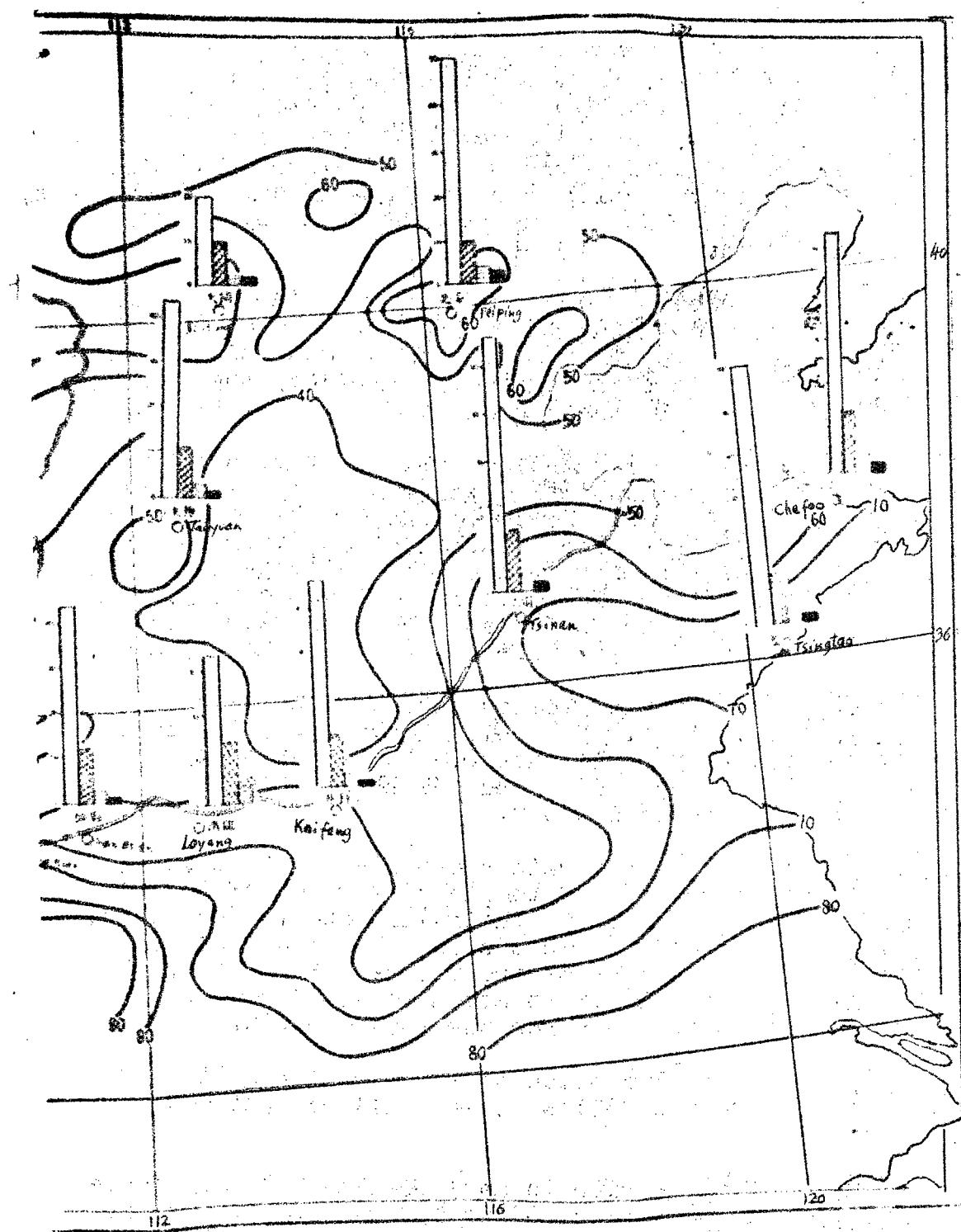


Figure 2 Average Number of Rainy Days per Annum and Average Frequencies of Light, Medium, and Heavy Rains Per Annum at Various Stations in the Yellow River Basin



The rainy days of the various stations in Figure 2 are divided into four types--light rain, medium rain, heavy rain and rain storms--according to the accumulated precipitation during each day. A daily precipitation of 0.1 to 10.0 millimeters is called light rain; that of 10.0 to 30.0 millimeters is called medium rain; that of 30.1 to 49.9 millimeters, heavy rain; that equivalent to or greater than 50.0 millimeters, a rain storm.

Evidently, the number of days with light rain are quite frequent in the Wei Ho Basin, generally being more than 70 days. And, there are as many as 96 days in Min Hsien, whereas there are only 19 days in Ta-t'ung. However, the general range is 30 to 80 days in the various areas of the basin.

The number of days with a medium rainfall varies only slightly between the various areas and generally is within the limit of 10 to 15 days. However, the northwestern part of the middle and upper reaches of the Yellow River has much fewer. For example, the area of the Ch'ing-t'ung-hsia gorge has only five days with medium rain in an average year. On the other hand, the Wei Ho Basin has more days with medium rain, totaling about 15 days, whereas Min Hsien has 17 days.

The various areas of the [Yellow River] basin have an average of about 0.5 to 4.5 days with heavy rain; the lower stretch of the river generally has 2.0 to 4.5 days; the northwestern part of the middle and the upper reaches of the river has only 0.55 to 1.0 day.

The number of days with a rain storm accumulation is also greater in the eastern part of the lower stretch of the river and in the mountain areas of the Ch'in-ling Shan. Such heavy precipitation seldom appears in the northwestern part of the middle and the upper reaches of the river. As a whole, the number of days with a rain storm accumulation varies within the range of none to two days for the entire basin.

The following is a discussion on the characteristics of the precipitation in the Yellow River Basin according to the seasons.

(1) Spring: Spring (March to May) precipitation is scarce, generally amounting to between 30 to 130 millimeters and accounts for only 10 to 20 percent of the annual amount of the various areas. In the Wei Ho Basin, especially in the areas of Min Hsien and T'ien-shui, spring precipitation is heavier

and averages 100 to 130 millimeters, which amounts to 20 to 25 percent of the local annual precipitation.

With the exception of the basins of the Lo Ho and the I Ho [in Honan Province], the regions in the Yellow River Basin generally have a spring precipitation of less than 100 millimeters. In Shansi and a vast section in Hopei the spring precipitation averages only about 50 millimeters, which amounts to 10 to 15 percent of the annual precipitation; it is definitely insufficient.

Spring precipitation in the Yellow River Basin is not only scarce but also varies greatly from year to year. A year with an annual precipitation less than average frequently occurs, and in the past when agricultural techniques were backward it frequently caused drought and famine.

The problems of drought will be treated in the third section of this article. Now let us discuss the weather conditions which lead to the formation of spring precipitation in this basin in order that the causes of insufficient spring rainfall may be better understood.

In March or early spring the warm and humid southeast air current from the oceans can hardly penetrate north of latitude 35° North (References 2, 3). Hence the humidity in the Yellow River Basin in spring is usually low. At this time the changes of weather in the Yellow River Basin are mainly under the influence of the westerly wind circulation in east Asia.

The wave motion of the westerlies in east Asia is particularly frequent in spring (Reference 4). Whenever a pressure wave passes through the basin from west to east, a warm horizontal current flows northward from the front of the low pressure trough while other air currents converge and ascend in front of the trough, sometimes resulting in a small amount of precipitation.

Since this northward-flowing warm horizontal current does not originate from the tropical maritime air masses but from the land surface-modified polar continental air masses (Reference 5), its original moisture content is not high. It is further depleted on the way northward after the air current has passed over the east to west running mountain ranges in central China such as the Ch'in-ling Shan, Fu-niu Shan, Ta-pieh Shan and other ranges. Therefore, it is

impossible for a large amount of precipitation to occur in front of the low pressure trough.

To the rear of the low pressure troughs there often occurs pronounced cold fronts because of the invasion of the cold horizontal current. Since cold air contains very little moisture, the precipitation near the cold front is often negligible, or it can even be that no precipitation takes place at all.

Furthermore, as the low pressure trough moves from the plateaux in the west over the Wu-t'ai Shan and T'ai-heng Shan to the North China Plain, the cold air in the rear of the trough sinks lower and lower, resulting in a condition not conducive to precipitation.

Weather maps of the past years indicate that in spring and autumn when the cold front reaches the North China Plain after passing over the plateaux and mountain areas in the north and the west, it either increases its southward shifting speed or becomes dissolved. As a result the cold front type of precipitation does not last in the lower reaches of the Yellow River.

As to the cyclones or the low depressions produced in the Yellow River Basin in spring, they generally do not become strong nor do they develop until they reach the ocean from the Chinese mainland. While on land, these cyclones or lows are very small in scope and their intensity is low. Sometimes the force of their wind may become stronger but the amount of precipitation produced is very small.

It is evident, therefore, that because of the characteristics of atmospheric circulation in east Asia, the conditions conducive to a large amount of precipitation in spring are non-existent in the Yellow River Basin (especially in the plain areas of the lower reaches) and hence that the scarcity of rain in spring has become a normal phenomenon in the areas.

The situation is further aggravated by the high annual variability of the westerly wind circulation (Reference 6). Spring precipitation in the basin thus becomes even more unlikely and the high frequency of spring drought is therefore not accidental.

(2) Summer: As mentioned above, the precipitation in this basin is highly concentrated in summer (June to August), and summer precipitation accounts for more than 50 percent of the annual amount in the various regions of the basin.

In those areas of insufficient spring precipitation mentioned above, such as the Hopei Plain, summer rainfall amounts to about 75 percent of the annual precipitation. In Shantung, Shansi and the southern part of Inner Mongolia, which are also regions with marked concentration of rainfall in summer, 60 to 70 percent of the annual precipitation falls in summer.

In the Wei Ho Basin, where the precipitation of spring and autumn is slightly heavier than in the other regions, the concentration of rainfall in summer is less marked and generally accounts for 40 to 50 percent of the annual precipitation. In the Lo Ho and the I Ho basins, summer rainfall accounts for about 50 percent of the annual amount, while in the middle and the upper reaches of the Yellow River it generally is 50 to 60 percent.

With the exception of the northwestern part of the middle and the upper reaches of the river, the average summer rainfall in the various areas of the basin is over 200 millimeters and it reaches more than 400 millimeters in Shantung and the northeastern part of Hopei.

The high concentration of rainfall in summer in the Yellow River Basin is due to the characteristics of the seasonal changes in the atmospheric circulation of east Asia. In summer the sub-tropical high pressure center over the Pacific is particularly well-developed and the western part of its high pressure ridge often extends to the east coast of China (Reference 7). Hence the warm, moist tropical maritime air masses may reach the various regions of this basin, especially the vast area in the middle and the lower reaches of the river.

In mid-summer when the maritime air masses prevail, the average position of their extreme fronts is well within this basin (Reference 8). Whenever cold air invades this basin from the north or the northwest, an extensive area with strong and heavy rain is produced near the cold front. If the cold front gradually becomes a stationary front in the basin, a rain storm or heavy rain belt occurs near the frontal area. The amount of precipitation during one fall

is considerable, often amounting to over 50 millimeters and possibly exceeding 150 to 200 millimeters.

Most of the rain storms in this basin occur in summer, especially in July and August, in spite of the fact that many still occur in September in the Wei Ho Basin (References 9, 10). The intensity of summer rain storms in the Yellow River Basin is relatively high and is of utmost importance to agriculture and water conservation work in the basin. Therefore, it merits further and more intensive studies.

At the moment let us turn our attention to a brief account of the localities where rain storms occur, the direction and the speed of the movement of rain storms, the types of rain storms and the amount of precipitation from them.

Figure 3 indicates that the frequency of rain storms is the highest in the plain areas on the western shore of the Po Hai, in the area between Lo yang and K'ai feng and in the higher areas of the Ch'in-ling Shan. These areas average one to two days a year with a daily precipitation over 50 millimeters. On the other hand, the northwestern part of the middle and the upper reaches of the river and the Ordos steppe average only one day or none at all with a daily rainfall with over 50 millimeters every ten years.

The principal directions in which the rain storm areas veer (shift) daily are three: from west to east, from southwest to northeast and from northwest to southeast (Fig. 3). However, in the mid-summer months of July and August the direction in which the rain storms shift is more complicated and the rain storms in the plain areas in the lower reaches of the river even shift northward.

[Legend]

- A. Main direction in the daily change (movement) of rainstorm area.
- B. Line of equal mean annual number of days with rainstorm.

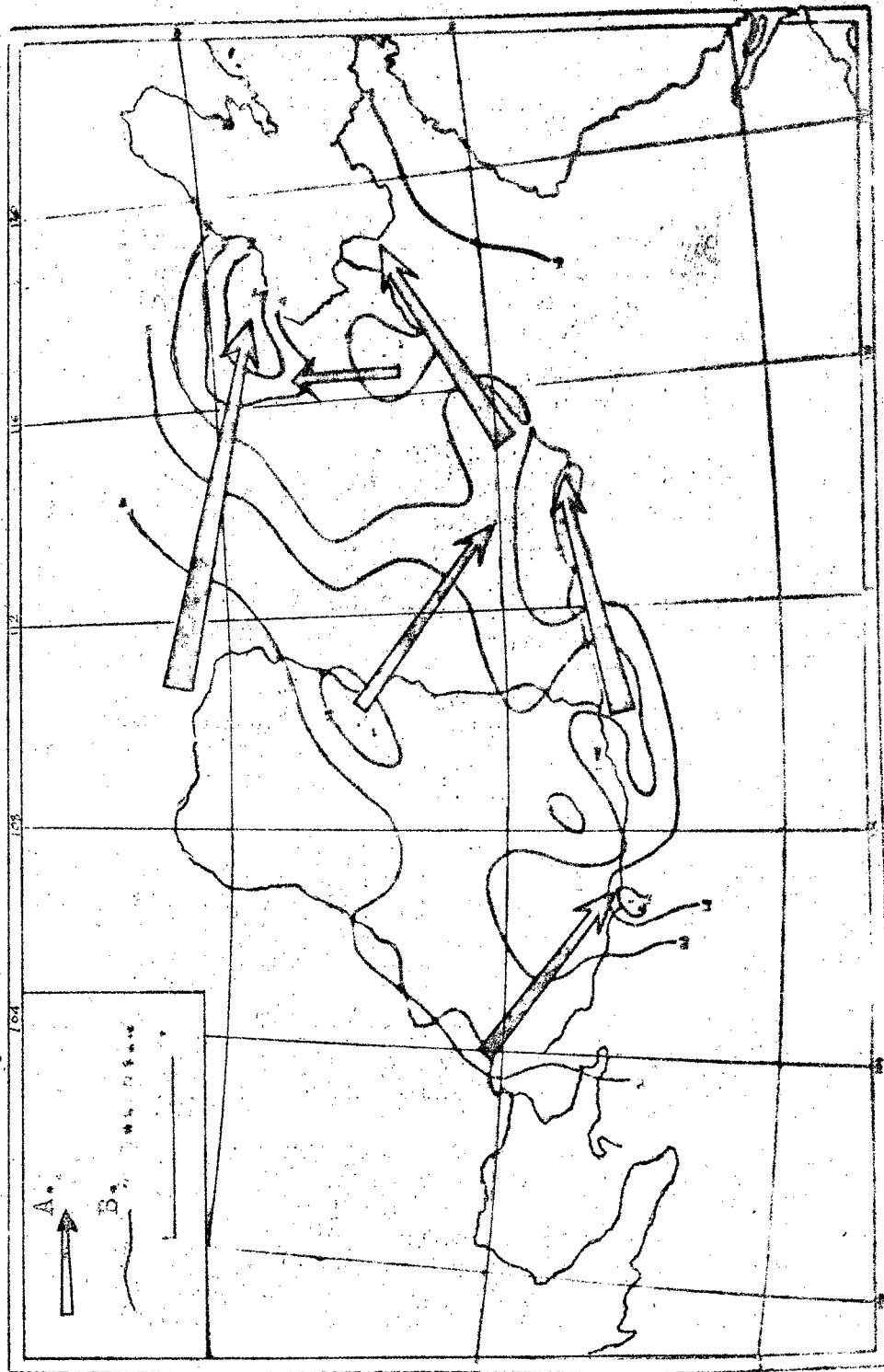


Figure 3 Frequency Distribution of Rainstorms and Main Directions in the Movement of Rainstorms in the Yellow River Basin

Generally speaking, the type of rain storms associated with a cold front generally shift from northwest to southeast; the stationary front type and the cold turbulence type generally shift from west to east or from southwest to northeast; and the typhoon type and those which occur at the west end of the Pacific high pressure ridge may shift from south to north.

The shift in direction of any particular rain storm is determined by the direction of the air circulation in the upper atmosphere and the weather system which produces that particular storm (Reference 11). (In Figure 3, the arrow heads point out only the main directions of shifting by rain storms; rain storms also exist and shift in areas unmarked by the arrow heads.) (Reference 9).

As to the velocity with which the rain storms shift in this basin Comrade HSU Meng-ying has done some statistical work in that respect (Reference 9). She pointed out that, "Rain storms generally shift slower in July and August; the average velocity is 150 kilometers per day for the various directions of shifting, even though a maximum velocity of more than 600 kilometers per day has been reached."

Comrade HSU also pointed out that, "Rain storms shift faster in May and June, moving at an average speed of 200 to 400 kilometers per day but the maximum speed is only about 500 kilometers per day."

Rain storms that do not change their positions every two days occur only from July to September. On the other hand, 80 percent of the rain storms in the Yellow River Basin last only one day and then dissolve. Only 15 percent of the rain storms in the basin last two days. Rain storms that last more than two days are still fewer. For this reason, the above-mentioned statistics on the directions and the speed of the rain storms can be applied only to about 20 percent of them which occur in the Yellow River Basin.

Of the types of rain storms, the frontal type is the most important and accounts for about 90 percent of the storms. On the other hand, the cyclonic type of rain storm is very rare and amounts to only five percent of the storms. The typhoon type of rain storm is still rarer in this basin and accounts for only two percent of the storms.

In addition to these three types, a small number of rain storms are due to the cold turbulence in high altitudes or other more complex causes. Of the frontal type of rain storms, the cold front type is the most numerous and accounts for two thirds of the total number. The stationary front type of rain storm comes next, and the warm front type is the least in number.

The summer rain storms often cause huge flood peaks in the rivers. The situation is particularly serious when a rain storm moves from the western to the eastern parts of the Yellow River Basin. As it moves, the intensity of precipitation continues to grow and the rain storm persists for a longer period. At the same time, the flood water of the middle and the upper reaches of the river flows towards the lower reaches, where the river channel is already heavily burdened with the huge amount of surface run-off. Thus a tremendous flood peak is produced in the lower reaches of the river.

For this reason it is imperative to analyze "the time, the area and the depth" of the large, strong and persistent rain storms in the Yellow River Basin. This writer once did some detailed work in this kind of analysis.

For example, in early July 1935 a strong rain storm occurred in this basin. It started in the Wei Ho and the upper reaches of the Ching Ho and then gradually moved eastward and lasted as long as a week. This storm persisted for four days (4 to 7 July) in the Wei Ho Basin and the total precipitation amounted to 2.57 billion cubic meters. Thus the average depth of rain during those four days of precipitation was 96 millimeters throughout the entire Wei Ho Basin (of 46,840 square kilometers).

This rain storm also persisted four days (6 to 9 July) in the drainage area of the Lo Ho, I Ho and Ch'in Ho (48,440 square kilometers). The average depth of precipitation was 115 millimeters and the total amount reached 5.56 billion cubic meters.

This rain storm also persisted five days (6 to 10 July) over a large area in the lower reaches of the Yellow River. On the five-day precipitation map (not included in this article) the 100-millimeter isohyet encircled an area amounting to about 110,000 square kilometers; the average depth of rainfall was 149 millimeters; and the total amount of precipitation amounted to 16.4 billion cubic meters.

On the six-day precipitation map (not included in this article) the total amount of precipitation within the area encircled by the 25-millimeter isohyet reached 27.56 billion cubic meters. If the precipitation beyond the area bounded by the 25-millimeter isohyet was included, then the total amount of precipitation would still be more impressive.

In early August 1937 a rain storm, which was even more intense than the one mentioned above, occurred and persisted seven days. On the seven-day precipitation map (not included in this article) the area bounded by the 150-millimeter isohyet amounted to about 100,000 square kilometers. The average depth of precipitation was 221 millimeters and the total amount of precipitation amounted to 23.4 billion cubic meters.

It should be pointed out that precipitation of various intensities also occurs most frequently in summer, despite the fact that summer precipitation is derived mainly from rain storms. The occurrence of heavy rain is very similar to that of rain storms. Medium rain and light rain also occur most frequently in summer.

However, in the Wei Ho Basin the frequency of light rain is lower in July and August than in April and May as well as in September and October. For further details readers may refer to pages 121 to 132 of "A Precipitation Atlas of the Yellow River Basin" and Chapter 5 of "The Precipitation of the Yellow River Basin" (Reference 12).

(3) Autumn: Autumn precipitation is very unevenly distributed and varies greatly in the various areas. For example, Heng-shui of the North China Plain averages only 38 millimeters of precipitation during the three autumn months. But autumn precipitation is particularly heavy in the Wei Ho Basin; for example it is 196 millimeters at Sian.

Most of the regions have an autumn precipitation of generally between 40 to 150 millimeters, which is slightly heavier than spring precipitation. The percentage of annual precipitation accounted for by autumn precipitation also varies greatly among the various regions in the basin. For example, it is only 15 percent in Heng-shui but reaches 34 percent in Sian. However, for most of the regions it is 15 to 30 percent.

Autumn precipitation is most unevenly distributed, especially in the autumn rainy area in the southern part of the Wei Ho Basin; this represents a marked characteristic in the autumn precipitation of this basin.

In September or early autumn, the chance of the southeast tropical maritime air masse to reach the Yellow River Basin is very low (References 8, 2), and consequently the precipitation of September is much smaller than that of the mid-summer months of July and August. Then why is the precipitation in September in the Wei Ho Basin and the Ch'in-ling mountain areas greater than that of August instead of less? This can be explained by the activities of the east Asia weather systems and their seasonal changes.

September is the period during which the east Asia atmospheric circulation abruptly changes from summer to autumn conditions (Reference 13); during this period the north polar continental air masses gradually become stronger and stronger and the likelihood of the Mongolian anticyclone invading the south greatly increases.

Whenever the anticyclone from Mongolia moves southeastward, the Wei Ho Basin is right in the southwestern sector of the anticyclone, and a SW- NE oriented low pressure trough often appears on the scene. Precipitation frequently occurs in that trough.

Furthermore, in September when the southeastward-moving cold front from the Ho-hsi Corridor [in Kansu] reaches the southern part of the Wei Ho Basin, it is intercepted by the Ch'in-ling mountain areas. As the speed of the cold front slows down, the frontal precipitation area is often enlarged.

The chance for this type of precipitation to occur in this area during the mid-summer months of July and August is less because during those two months the anticyclonic circulation in the upper air over the eastern part of the Tibetan Plateau dominates (Reference 3) and extends its influence over a part of Szechwan and Shensi provinces. This lessens the chance for the northwest cold air to invade this area.

Furthermore, this more stable anticyclone may effectively prevent air currents coming from various directions from converging over the Wei Ho Basin. In September the conditions of the summer atmospheric circulation change suddenly and these changes favor precipitation in the Wei Ho Basin. Hence

the precipitation for September in this area is even heavier than that of July or August.

Autumn precipitation in Hopei and a greater part of Shansi Province is always less than summer precipitation, generally being only 40 to 90 millimeters, which is about the amount of spring precipitation. The scarcity of rainfall in autumn and in spring is due to similar causes which have been dealt with in the preceding pages. Another cause is this: in autumn the pressure wave movement of the westerly wind belt is not constant and the upper air of the northern part of the middle and the lower reaches of the river often consists of a warm high pressure ridge, resulting in the so-called "fine and dry autumn weather", which is not conducive to precipitation.

The amount of autumn precipitation in the middle and lower reaches of the river is derived mainly from the moisture released by the modified maritime air masses along the cold front in September before the changes in the summer atmospheric circulation take place.

(4) Winter: Winter precipitation is very scarce and generally between 5 to 35 millimeters, which is less than 5 percent of the annual precipitation in most areas. Even in areas where winter precipitation is slightly heavier, such as K'ai feng (32 millimeters) and T'ung-kuan (31 millimeters), it amounts to only 5 to 6 percent of the annual figure.

Winter precipitation in this basin is chiefly in the form of snow. Throughout the entire basin snowfall is never heavy, and the successive days with snow are few and far between. According to the statistics of the last five years (1951 to 1955), the average number of days with snowfall per annum is generally below 15 in the various areas of the Yellow River Basin (Fig 4).

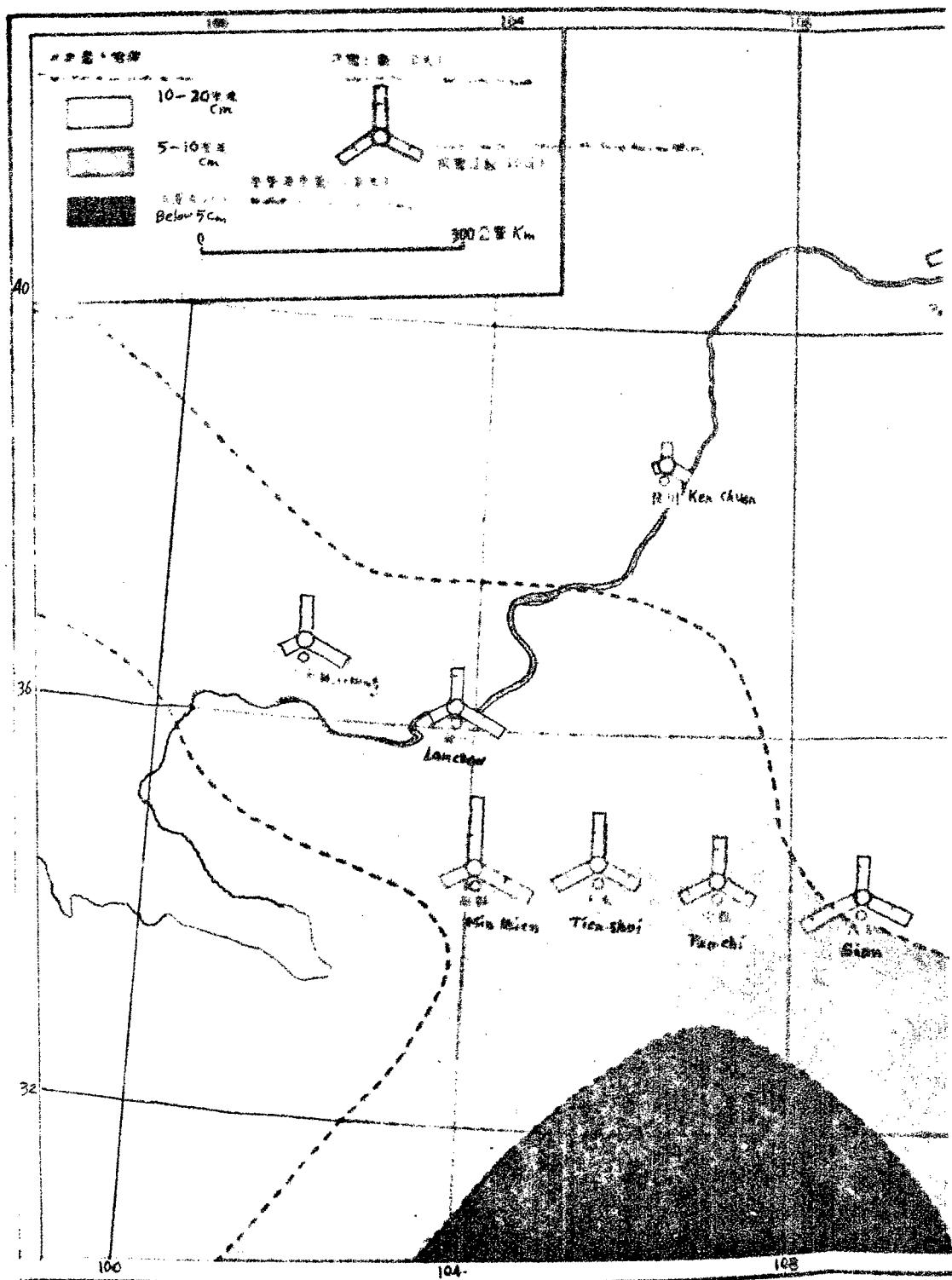
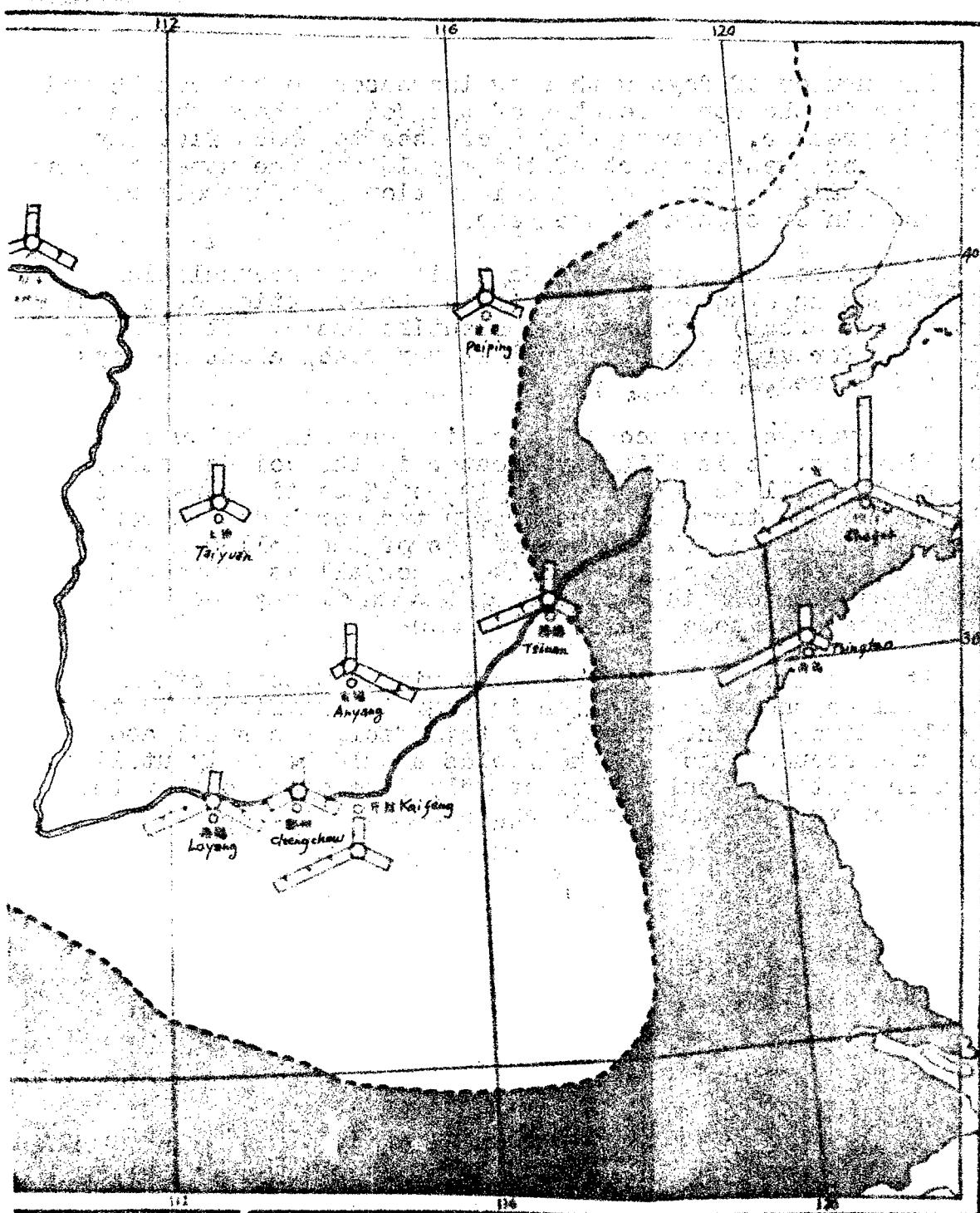


Figure 4 Distribution of Winter Precipitation and Depth of Snow Accumulation in the Yellow River Basin



The number of days with snow increases to between 15 and 20 days in the upper reaches of the Wei Ho where the snowfall is greater, whereas they decreases to about five days in the northwestern part of the middle and the upper reaches of the Yellow River where precipitation is extremely rare in the winter season of the year.

Therefore, the number of days with snow accumulation per annum is also very small (with the exception of the high mountain areas) throughout the entire basin. It is 10 to 20 days for most areas, though it may reach about 25 days in a few areas.

The average snow accumulation is generally below ten centimeters. It is slightly greater in the Wei Ho Basin, where it still is no more than 10 to 15 centimeters. It is only about three centimeters in the northwestern part of the middle and the upper reaches of the Yellow River. The average depth of the heaviest snowfall is between 5 to 20 centimeters in most areas, though it may reach 25 centimeters in some areas.

It is evident, therefore, that winter precipitation as well as snow accumulation is very insignificant in the Yellow River Basin. In view of this fact, the small amount of snow accumulation in the fields should be fully utilized and irrigation should be vigorously developed so that the yield of the autumn-planted crops may be increased.

III. Characteristics of the Annual Variation of Precipitation in the Yellow River Basin

As shown in Figure 5, precipitation in the Yellow River Basin has as another remarkable characteristic a very high annual variability. The relative variation rate ^{1/} in annual precipitation is generally over 20 percent and even over 30 percent in areas north of a line connecting T'ung-kuan and K'ai feng. The area with the lowest relative variation rate in annual precipitation in this basin is located in the southwestern part of the middle and the upper reaches of the Yellow River. For example, the relative variation rate in annual precipitation in the vicinity of Min Hsien is less than 15 percent.

^{1/} Relative Variation Rate in Annual Precipitation = the average departure in precipitation/mean precipitation for the same period x 100 percent ("Mean Precipitation" is the average of many years' precipitation records at the locality. "Departure" is the difference between the annual precipitation in a certain year and the mean precipitation. "Average Departure" is the average of many years' departures.)

[Legend]

- A. Precipitation Variation Rate
- B. Line of equal variation rate in annual precipitation (%)
- C. (Number between 2 columns denotes the ratio between the maximum and the minimum precipitation)

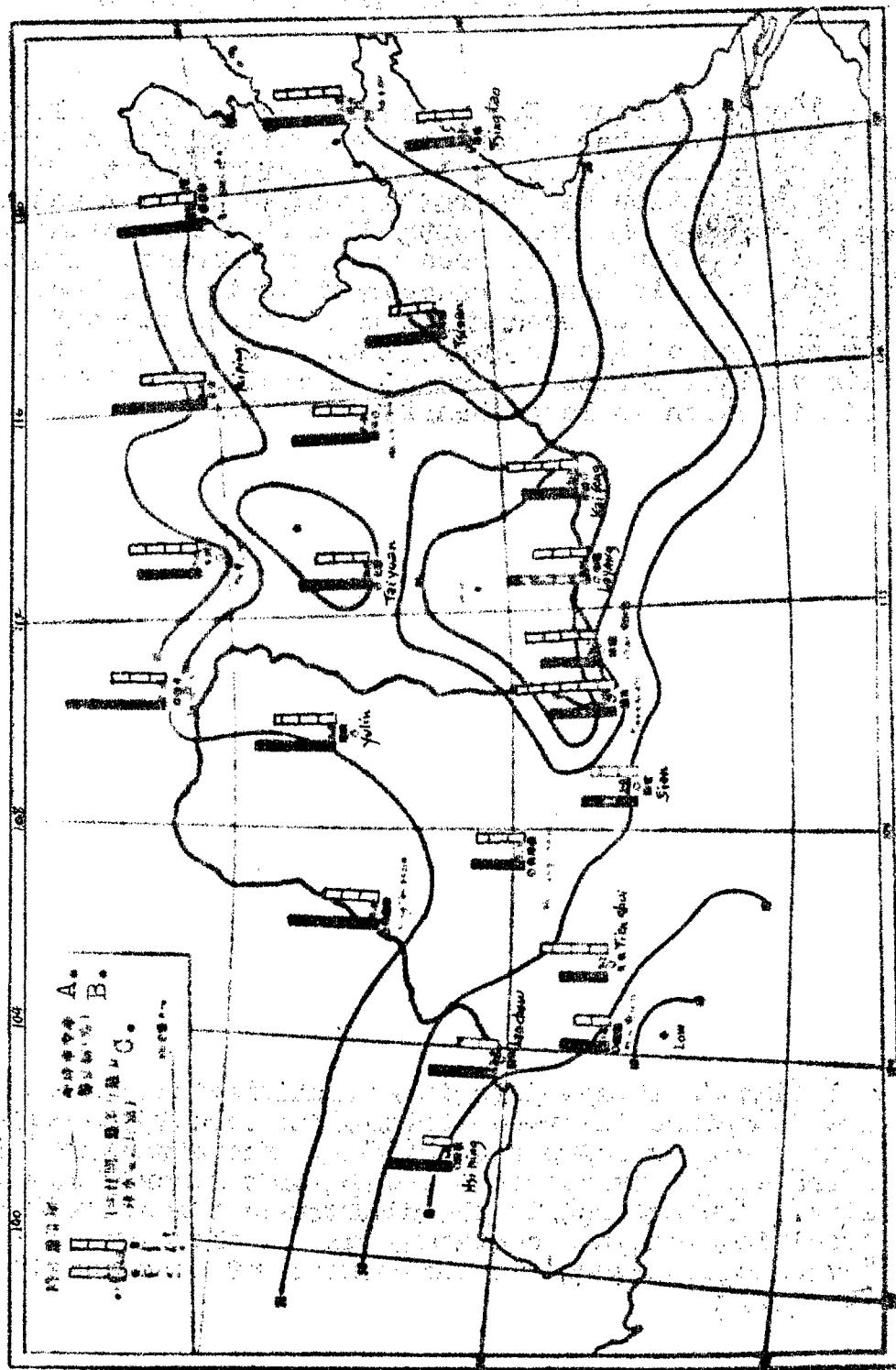


Figure 5 Distribution of Variation Rates in Annual, Spring and Summer Precipitation in the Yellow River Basin

The relative variation rate in spring precipitation is very high. In most areas the spring rate approximately doubles the annual rate and in many others the spring rate surpasses the annual rate by 40 percent. For example, at Ss-la-ch'i and Peiping and other localities the variation rate for spring is even greater than 50 percent.

The region with the lowest variation rate for spring lies in the area of T'ien-shui and Min Hsien in the upper reaches of the Wei Ho where the spring rate of variation is about 25 percent. However, in K'ai feng, Ta-t'ung, T'ung-kuan and other localities where the annual variation rate is high, the spring variation rate, on the other hand, is slightly lower and generally below 40 percent.

The relative variation rate in summer precipitation generally is slightly lower than that of spring precipitation. It is about 25 to 40 percent. It is particularly low in Hsi-ning, Min Hsien and other localities; the summer variation rate being below 20 percent. In the above-mentioned localities (K'ai-feng, Ta-t'ung, T'ung-kuan and so on) where the annual variation rate is high and the spring variation rate is slightly lower, the summer variation rate is remarkably high at 35 to 45 percent. Since the precipitation in this basin is highly concentrated in summer, there is a great similarity between the relative variation rate in summer precipitation and the annual precipitation.

The ratio between the annual precipitation of the year with the highest rainfall and that of the year with the lowest rainfall in the various areas of the basin is related to the amount of the relative variation rate in annual precipitation. For example, in the southwestern part of the middle and the upper reaches of the river where the annual variation rate is low, the ratio is about 1.5 to 2.5; in the lower reaches of the river where the annual variation rate is high as in T'ung-kuan and K'ai feng, the ratio is as high as 5.5 to 7.5; and in the remaining areas, the ratio generally is 2.5 to 4.0.

In various regions the maximum range of variation in annual precipitation is equivalent to the amount of difference between the year with the highest precipitation and that with the lowest precipitation. It also varies greatly among the regions in the Yellow River Basin.

The range of variation generally surpasses 500 millimeters in the plains areas in the lower reaches of the river and may reach the maximum of about 1,000 millimeters (in Tsingtao, Peiping and other localities). However, it is less in the light-rainfall area in the southern part of Hopei Province. For example, in Heng-shui (17 years' records) the maximum range of variation is less than 400 millimeters.

In Shansi and northern Shensi the maximum range of variation is generally 300 to 500 millimeters. It is about 400 to 600 millimeters in the Wei Ho Basin in southern Shensi. In the area from Min Hsien to Hsi-ning in the southwestern part of the middle and the upper reaches of the river, the range of variation is the smallest, about 200 to 300 millimeters.

Generally speaking, the annual variation of precipitation in the Yellow River Basin is not only high but also varies greatly among the areas--between the eastern and the western parts, between the northern and the southern parts--as well as between the plains and the mountain areas. Furthermore, the seasonal variations also vary greatly.

III. Drought in the Yellow River Basin

As stated above, precipitation is unevenly distributed throughout the Yellow River Basin. The annual precipitation is not bountiful at many localities and is generally below 500 millimeters in most of the regions; and the amount of annual precipitation in various regions is chiefly dependent on rain storms and heavy rain in summer. Hence, drought in the Yellow River Basin has become an outstanding problem.

At this juncture, let us discuss the drought problem of the Yellow River Basin in the light of the occurrence of drought areas (Reference 16) and the conditions under which drought months, drought seasons and drought periods occur in the various regions of the basin (Reference 15).

If a drought month is defined as a month having a precipitation equivalent to or below 40 percent of the average precipitation for that month in a certain locality or region, then the various localities or regions in the basin may, on

the average, experience one or two such months every year.

The percentage of occurrence of drought months in various seasons varies from place to place (Fig 6). Generally speaking, it is the highest in winter, generally above 30 percent or even above 50 percent (as in T'ien-shui), and it is the lowest in summer, generally below 20 percent or even below 10 percent (as in Peiping); however, it varies considerably between spring and autumn in the various localities. For example, in Peiping drought months occur more frequently in spring than in autumn (32 percent to 23 percent), whereas in Tsinan they occur more frequently in autumn than in spring (33 percent to 26 percent).

In Tsinan the chance of a drought month occurring in autumn is even greater than in winter. On the contrary, in T'ien-shui of the Wei Ho Basin the percentage of drought month occurrence is the smallest in autumn, being less than 10 percent; however, it is the largest in winter, amounting to about 50 percent; and it is about 20 percent both in spring and summer, even though it is slightly higher in spring than in summer.

It is evident, therefore, that there is no uniformity in the occurrence of drought months in the various seasons among the localities in this basin.

In various localities periods without sufficient precipitation often persist for several months, thus possibly resulting in severe droughts. If a month without sufficient precipitation is defined as one having a precipitation equivalent to or below 60 percent of the average precipitation for that month of the year, then the period without sufficient precipitation may persist longer than four months in the various localities in this basin (The longest one lasted) only three months in T'ien-shui, on the basis of 15-year records).

According to available records, the longest period without sufficient precipitation occurred in Peiping; for nine consecutive months the monthly precipitation was below 60 percent of the average. However, a period without sufficient precipitation very seldom persists six months or longer in the various localities, even though such a lengthy period may occur once every 20 years.

[Legend] A. Percentage of frequency for spring to become a drought season.
B. (A drought season is one with a precipitation of 0 to 40 percent of average).
C. Percentage of drought months in various seasons.

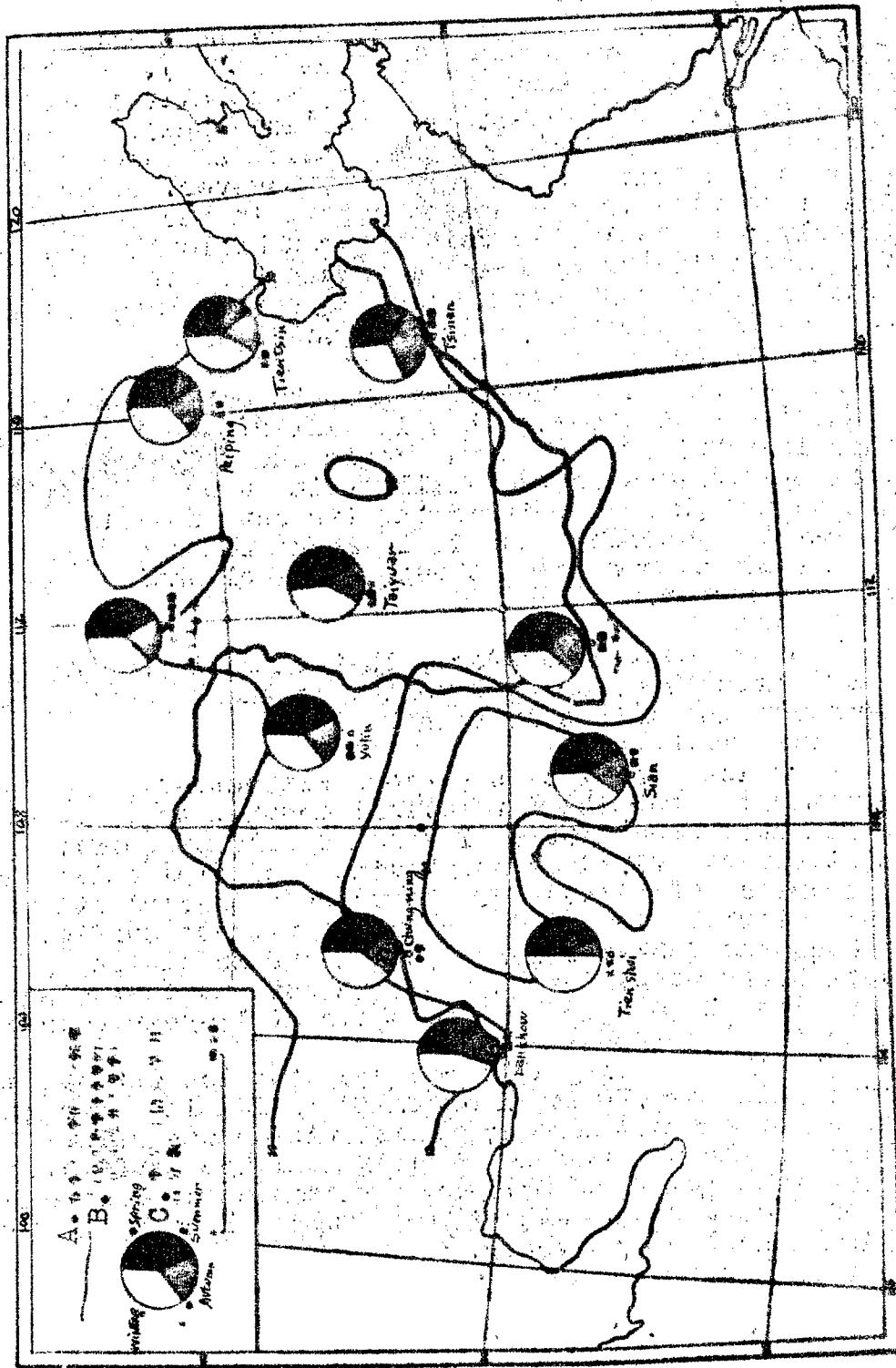
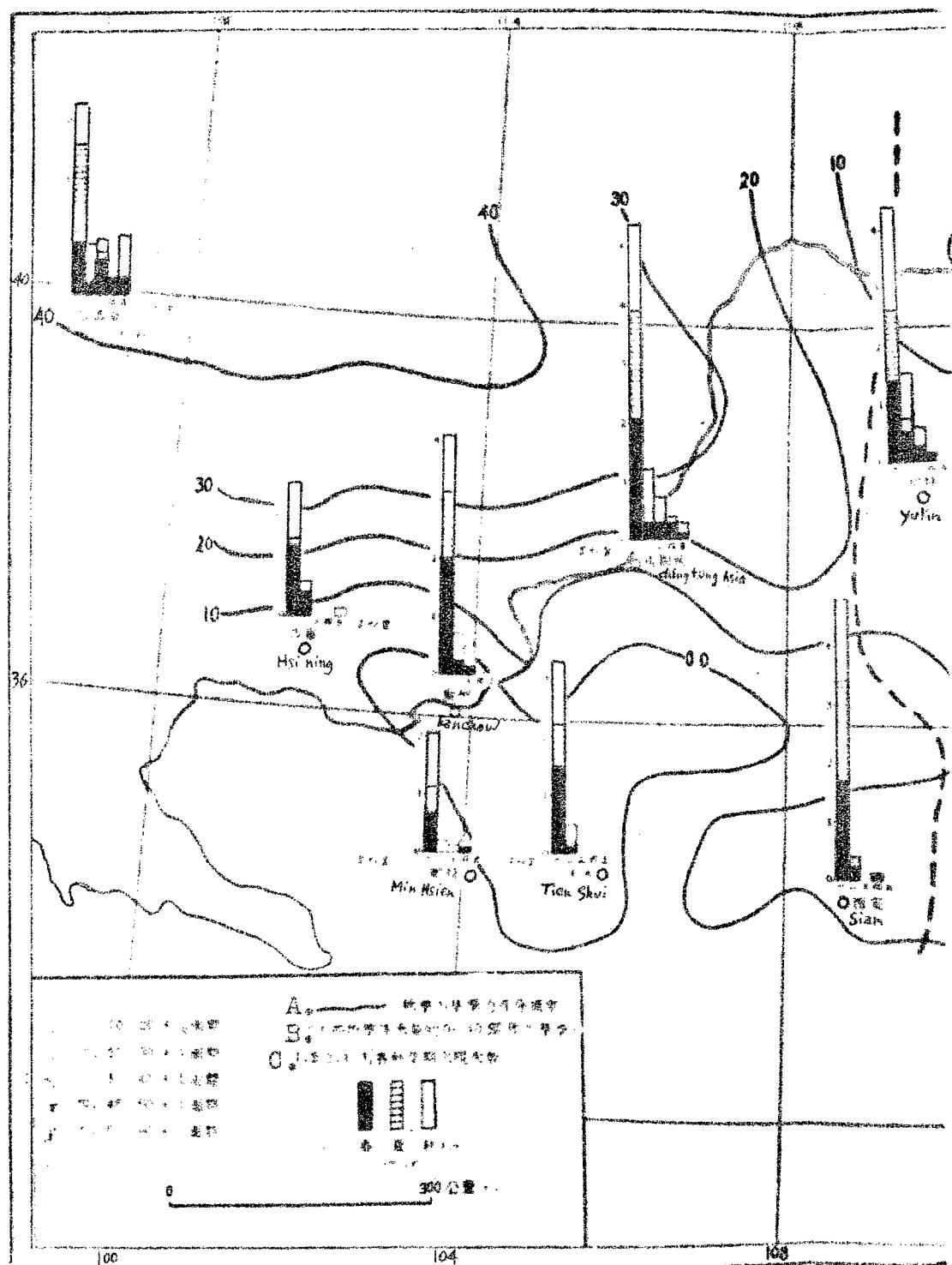


Figure 6 Seasonal Distribution of Drought Months at Various Localities in the Yellow River Basin



[Legend]

Period of Scarce Rainfall

- I. 10-20-day period
- II. 21-30-day period
- III. 31-45-day period
- IV. 46-60-day period
- V. 61-90-day period

- A. Percentage of frequency for autumn to become a drought season.
- B. (A drought season is one with a precipitation of 0-40% of average)
- C. 1, 2, 3, 4 denote number of occurrence of various drought periods.

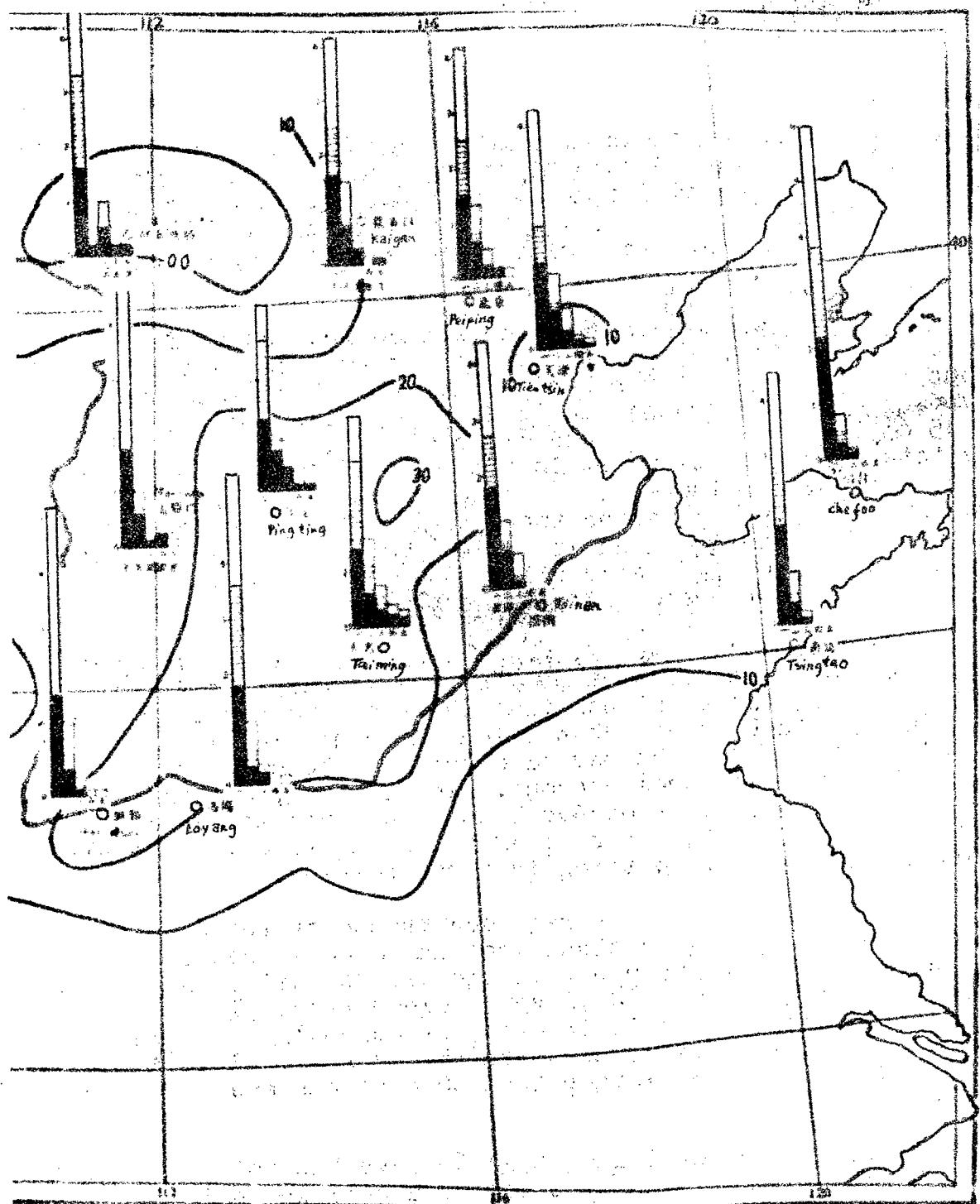


Figure 7 Occurrence Frequencies of Various Drought Periods in Spring, Summer and Autumn in the Yellow River Basin

If a drought season is defined as one having a seasonal precipitation below 40 percent of the average amount for that season, then the frequency of a drought season is higher in autumn than in spring (Figs 6 and 7) in the various localities in the basin, particularly in the upper reaches of the river.

Figure 7 shows the average occurrence frequency of drought periods in spring, summer and autumn at 20 observation stations in the Yellow River Basin. The drought periods are divided into five groups, 10 to 20 days, 21 to 30 days, 31 to 45 days, 46 to 60 days and 61 to 90 days. That is, if the total precipitation within a period of 10 to 20 days is less than 0.1 millimeter the period is considered as a drought period. Any period that falls between two 10 to 20-day drought periods and during which the total precipitation is less than 0.5 millimeter will be incorporated so as to make up a drought period of more than 20 days.

As indicated in Figure 7, the average occurrence frequency of the 10 to 20-day drought period varies among the localities but generally is higher than those of the longer periods. For example, in Lo yang, Shan Hsien and other localities the 10 to 20-day drought period occurs on the average more than five times in three seasons. In Hsi-ning, Min Hsien and other localities it occurs less than three times in three seasons; and in the rest of the localities it generally occurs three to five times in three seasons.

In all localities the average occurrence of the 21 to 30-day drought period is about once in three seasons, and it occurs the least frequency in the Wei Ho Basin. A drought period of longer than 30 days very seldom takes place in the various localities; if it does, it generally does so less than once in three seasons on the average. In T'ien-shui no drought period longer than 30 days has ever occurred so far.

A drought period of longer than 60 days has not yet occurred in summer in any area of the basin, and only in spring or autumn does such a period occur, and that is occasional. However, the Wei Ho Basin and Shantung Province have not yet experienced a drought period longer than 60 days even in spring or autumn.

[For the following analysis] the Yellow River Basin is divided into eastern and the western parts along latitude

109° East (see the black broken line in Fig 7). The number of times in which widespread scarcity of rainfall and widespread abundant rainfall occurred in the eastern part during the various months from 1920 to 1954 (two of these years are without records) are listed in Table 1, and similarly the incidence of occurrence for 1933 to 1954 in the western part of the basin are listed in Table 2.

In these two tables, the following facts stand out: (1) No matter if it be in the eastern or the western parts, the occurrence frequency of widespread scarce rainfall and widespread drought far surpasses that of widespread abundant rainfall. This clearly indicates that vast expanses of territory in this basin often experience a scarcity of rainfall simultaneously, and hence the drought areas are very extensive. Abundant rainfall is very rarely widespread and usually occurs only locally. The expression "Drought occurs in a patch; flood, on a line" corresponds with the facts.

(2) Months with a normal amount of precipitation in particular occur frequently in the western part but very rarely in the eastern part. This corresponds with the fact that in the Yellow River Basin the relative variation rate in precipitation is generally lower in the western part (especially in the Wei Ho Basin) than in the eastern part.

(3) In terms of the aggregate frequency of widespread scarce rainfall and widespread drought, the eastern part has the highest frequency in November and the western part in December; and the eastern part has the lowest frequency in July and June, and the western part in July, September and April. In the same terms, the eastern part has a higher incidence of these conditions in the mid-spring month of April and the mid-autumn month of October (the frequency of occurrence in these months is identical), whereas the western part has a greater occurrence of such conditions in the late spring month of May and June than in the late autumn month of November.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Widespread Scarce Rainfall*	2	3	2	4	5	3	5	4	3	6	2	42	
Widespread Drought Rainfall	6	3	4	4	1	2	1	1	2	5	6	8	43
Widespread Abundant Rainfall	1	2	3	0	1	1	0	1	1	2	3	2	17
Widespread Normal Rainfall	0	3	0	0	0	2	1	4	0	0	2	1	18

Table 1 [For the eastern part of the Yellow River Basin]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Widespread Scarce Rainfall*	1	2	4	0	4	4	1	2	1	3	2	4	28
Widespread Drought Rainfall	5	1	0	1	1	1	0	0	0	1	3	3	16
Widespread Abundant Rainfall	0	1	0	0	0	1	0	0	0	0	0	0	2
Widespread Normal Rainfall	1	3	5	4	2	4	2	3	2	3	3	3	34

Table 2 [For the western part of the Yellow River Basin]

* Tables 1 and 2 are based on statistics obtained from maps showing the distribution of precipitation grades, which are kept in the material room of the Central Meteorological Observatory. "Scarce Rainfall" denotes Grade 2 to 3; "Drought," Grade 1 to 2; "Normal Rainfall," Grade 4 to 5 and "Abundant Rainfall," Grade 6 to 7. As to the method of grading readers are advised to consult Reference 18.

In terms of widespread drought alone, the eastern part has a higher frequency of occurrence during the period of October to April and lower ones in the period of May to September; whereas the western part has a higher frequency from November to January and a lower one from March to October, especially during the period from July to September. In the western part of the basin no drought has ever occurred during the latter period for the last 22 years.

From 1920 to 1954 (Two of these years are without records) the months in which scarce rainfall or drought was widespread in the eastern part number 85 (Table 1), averaging 2.6 months per annum. Of these 85 months, periods of two consecutive months appeared 10 times, and those of three consecutive months and four consecutive months appeared twice each; with all such combination accounting for 40 percent of the 85 months.

In the spring of 1935 and 1940, the eastern part had three consecutive months of widespread scarce rainfall or drought; this reflects the severity of extensive spring drought in the eastern part of the basin. And, widespread abundant rainfall occurred a total of six times in the month either immediately preceding or following the months of widespread scarce rainfall or drought. These six times amounted to 35 percent of the total of 17 times during which widespread abundant rainfall occurred; and on all 17 occasions the rainfall was independent.

From 1933 to 1954, the months with widespread scarce rainfall or widespread drought in the western part total 44, averaging 2 months a year, which is slightly less than in the eastern part. Of these 44 months, periods of two consecutive months appeared seven times, and those of three consecutive months, twice; these two groups accounted for 20 out of the total. The remaining 24 months occurred singly.

Of these 44 months in which scarce rainfall or drought was widespread, a period of three consecutive months appeared once from March to May 1941 and again from December 1941 to February 1942.

Of the 34 months with widespread normal rainfall, only four occurred in the month either immediately preceding or following the months in which scarce rainfall or drought was widespread. This underscores the fact that the chance for a month with widespread normal rainfall to occur immediately

after a month with widespread scarce rainfall or widespread drought is very low in the western part of the basin.

IV. Conclusions

According to the preceding sections, the precipitation of the Yellow River Basin may be characterized by the following five main characteristics: (1) severe spring drought, (2) concentration of summer precipitation and violent rain storms, (3) autumn precipitation varies greatly from place to place, (4) winter precipitation insufficient and chiefly in the form of snow, and (5) high annual and seasonal variations.

On the basis of the foregoing characteristics of the precipitation in the Yellow River Basin, the following two preliminary measures are suggested: (1) the advanced experiences of the Soviet Union should be adopted so that the small amount of snow accumulation in the fields in winter may be utilized to the utmost; wells should be dug extensively and irrigation measures vigorously developed in order to prevent spring drought, and (2) the water conservation plan for the lower reaches of the Yellow River should be given proper attention and facilities provided in order to store the large amount of summer precipitation in the lower reaches in an effort to prevent flood and to facilitate irrigation.

Finally, our most heartfelt acknowledgement is hereby made to Comrade CHANG Chih-ying for assistance in computation and cartographic work.

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